INVESTIGATING BEHAVIORAL AND HABITAT-USE PATTERNS OF SPINNER DOLPHINS (STENELLA LONGIROSTRIS) IN THE MAUI NUI REGION USING ACOUSTIC DATA

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Abstract

Spinner dolphins (*Stenella longirostris*) rest during the day in nearshore areas where they are susceptible to human disturbance. Due to concerns over the negative impacts of human activity, the Pacific Islands Regional Office of NOAA Fisheries proposed a 50-yard approach and swim-with limit for spinner dolphins with the potential for time-area closures. A combination of passive acoustic monitoring and vessel surveys was employed to establish an understanding of spinner dolphins' current use of the Maui Nui region (Maui, Molokaʻi, Lānaʻi, and the ʻAuʻau channel). Ecological acoustic recorders (EARs) were deployed in eight locations in Maui Nui, and one well-established resting bay off west Oʻahu for comparison. The amount of whistles, clicks, and burst pulses in each recording were quantified by an acoustic activity index (AAI) and averaged by the hour of the day.

The deployment, time of day, and interaction between longitude and latitude were significant predictors of variation in dolphin acoustic activity. Acoustic activity was greater at the Oʻahu site than any of the Maui Nui sites, and was greatest between sunrise and noon. Acoustic activity at the Maui Nui sites indicated, and vessel surveys confirmed, that spinner dolphins exhibited resting behaviors in the ʻAuʻau channel between Maui and Lānaʻi, and along west Maui, and southeast Lāna'i. Dolphins resting in the channel is unique to Maui Nui and has not been described along Hawaiʻi Island or Oʻahu. Because spinner dolphins use the coastlines and the channel to rest in Maui Nui the 50-yard approach limit would be a more feasible management option for the region than time-area closures.

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Introduction

The spinner dolphin (*Stenella longirostris*) is a well-studied odontocete species found throughout the Hawaiian island chain. Hawaiian spinner dolphins are considered genetically distinct from other populations in the Pacific Ocean (Andrews et al., 2010). Within the Hawaiian Islands, spinner dolphins are regularly found around Kure Atoll, Midway Atoll, Pearl & Hermes Reef, and the French Frigate Shoals of the Northwestern Hawaiian Islands, as well as all the Main Hawaiian Islands (Niʻihau, Kauaʻi, Oʻahu, Molokaʻi, Lānaʻi, Kahoʻolawe, Maui, and Hawaiʻi Island). Population genetic analyses published in 2006 revealed that spinner dolphins in the Kure Atoll, Midway Atoll, and Pearl & Hermes Reef of the Northwestern Hawaiian Islands formed one distinct interbreeding group (Andrews et al., 2006). Genetic differentiation was found between the Kona Coast of Hawaiʻi Island and all the other islands, including Maui, which lies only 46 km away (Andrews et al., 2010). There was little genetic distinction between Kure and Midway Atolls, and between French Frigate Shoals, Niʻihau, Kauaʻi, and Oʻahu. Additionally, French Frigate Shoals and Oʻahu had the highest inferred migration rates based on the number of individuals with genetics more similar to those found on an island other than the one from which they were sampled (Andrews et al., 2010).

Currently, six stocks of Hawaiian spinner dolphins are recognized in the U.S. Exclusive Economic Zone (EEZ) based on population genetic analyses. The island-associated stocks extend up to 10 nautical miles (nm) from shore: Hawaiʻi Island, Oʻahu/4-islands, Kauaʻi/Niʻihau, Pearl and Hermes Reef, Midway Atoll/Kure. Spinner dolphins found beyond 10 nm, but within the EEZ are considered part of the Hawaiʻi Pelagic stock, which includes the population at French Frigate Shoals (National Oceanic and Atmospheric Administration [NOAA], 2012). The best estimates of population size by stock tend to be based on surveys in small geographic areas of the islands conducted 10-15 years ago and are therefore likely underestimations of the true population sizes. The estimated population size of the Hawai‘i Island stock based on a survey of the leeward coast is 790 (CV=0.17) dolphins (Hill et al., 2011). The O‘ahu/4 Island stock has an estimated population of 355 (CV=0.09) based off of a 2007 survey effort on the leeward side of O‘ahu (Hill et al., 2011). The population estimate for the Kaua‘i/Ni‘ihau spinner dolphin stock is 601 (CV=0.2). This estimate was based off of a 2005 survey on the leeward coast of Kaua‘i (NOAA, 2012). There are no current estimates for the populations at Pearl and Hermes Reef, Midway Atoll/Kure, or the Hawai‘i Pelagic stocks (NOAA, 2012). A 2002 shipboard line-transect survey of the entire Hawai‘i EEZ estimated the Hawaiian spinner dolphin population to be 3,351 (CV=0.74), however this estimation is outdated and likely also an underestimate (Barlow, 2006).

Past research off the Kona coast has established that spinner dolphins are reliably found along Hawai‘i Island’s sloping coastlines where they follow predictable, daily behavioral routines (Norris et al., 1994). These cycles consist of nocturnal foraging offshore, and a return to shallower waters to rest during the day (Norris et al., 1994). Spinner dolphins feed on vertically migrating mesopelagic fish, and mesopelagic and epipelagic squid typically found in deeper waters of the island slopes near the 1000-fathom contour (Klinowska, 1991; Norris et al., 1994; Benoit-Bird et al., 2001; 2003). By dawn, the dolphins transition to a bout of increased aerial activity followed by zig-zag swimming in which the dolphins frequently change the direction of their swimming (Norris et al., 1994). The highly dispersed school begins to tighten into subgroups as it moves into shallower, protected bays to rest (Norris et al., 1994).

Aerial surveys off the Kona coast in 1979-1980 suggested that bay selection was opportunistic and showed a positive correlation between the closeness of deep water to shore and the presence of dolphins in nearby coves (Norris et al., 1994). However these surveys also showed that if visibility or weather conditions were poor, the dolphins would relocate to calmer bays. While in the bays, spinner dolphins confine their movements to areas over white coral sand and avoid dark reefs. This preference for shallow bays with low rugosity has also been demonstrated in modeling of spinner dolphin habitat in the Main Hawaiian Islands (Thorne et al., 2012). The need for clear visibility is attributed to the dolphins' shift from primarily employing echolocation to monitor their environment, to relying more on vision in the resting state (Norris et al., 1994).

Since these surveys, it has been observed that groups of spinner dolphins off the islands of Hawaiʻi, Lānaʻi, and Oʻahu show site fidelity and exhibit these predictable patterns of behavior (Benoit-Bird et al., 2003; Bazúa-Durán & Au, 2004; Lammers et al., 2004; Tyne et al., 2014; M.O. Lammers, pers. comm., 2015). However, there is another, more cryptic group that occupies the coastline along west Maui. This group is commonly seen in the broader Maui Nui area (between Maui, Molokaʻi, and Lānaʻi), but their behavioral use of the coastline and inter-island channels is variable and poorly understood. This area is of particular interest because Maui Nui has a uniquely shallow bathymetry compared to the steeper island slopes where the Hawaiʻi Island, Lānaʻi, and Oʻahu spinner dolphins occur (Price & Elliot-Fisk, 2004). Therefore, it is unclear how these dolphins complete their day/nighttime behavioral cycle, given the relatively far distance to deep, island-slope waters. It is unknown whether this stock of spinner dolphins expend more energy to travel the extra distance to the island slopes off west Lānaʻi or if they exploit another source of prey.

In addition, the west Maui coast has been subject to intense urbanization and human activity over the past three decades with the construction of numerous resorts and the growth of recreational water activities. These activities, which include whale-watching tours, snorkeling tours, parasailers, and recreational boaters, mostly occur in the shallow waters typically preferred by spinner dolphins for daytime resting. This is a concern because human activity can disturb dolphins and interrupt their resting periods or displace them from their prime resting locations (Tyne et al., 2014).

Previous research in Shark Bay, Australia showed that an increase in the number of dolphin tour vessels led to a significant decrease in the abundance of bottlenose dolphins (Bejder et al., 2006). Studies conducted off the Kona coast of the Island of Hawai‘i have shown that human activities frequently interrupt dolphins at rest, and bays with dolphin-centric human activities have greater amounts of dolphin acoustic activity, suggesting a reduction in rest (Courbis & Timmel, 2009; Heenehan et al., 2016a, 2016b). Dolphins off Mākua Beach, O‘ahu have also shown a decrease or delay of rest possibly in response to swimmers (Danil et al., 2005). These interruptions are important to note since spinner dolphins that have been displaced from a resting bay are thought to be unlikely to enter a resting state elsewhere (Tyne et al., 2015). Spinner dolphins are also less resilient to human disturbance because of their consistent daily behavioral cycles which cause their resting behavior to take place near human activities (Tyne et al., 2017).

Recently in the Hawaiian Islands, the National Marine Fisheries Service proposed a 50-yard approach limit for spinner dolphins in the wake of concerns over the possible negative impacts of human disturbance (NOAA, 2016). In order to measure the efficacy of any implemented regulations, there needs to be a baseline of current spinner dolphin habitat-use and behavior patterns for comparison. The aim of this study is to provide this baseline information, and examine if the dolphins in Maui Nui are exhibiting signs of adapting to habitat loss of prime resting locations due to coastal development or boating activities. This analysis has the potential to reveal behavioral trends that reflect the impacts of past and current human activities, and when compared to studies conducted after the implementation of the new regulations, it can be used to determine whether the regulations have had an impact on increasing spinner dolphin resting behavior in areas affected by human activity.

To answer these questions and understand the habitat-use patterns of spinner dolphins in Maui Nui, a combination of passive acoustic methods and vessel surveys were employed. Spinner dolphins are an acoustically active species and their presence can be monitored by autonomous recorders (Lammers & Munger, 2016). Passive acoustic monitoring and visual survey methods have been shown to produce equivalent results in presence/absence studies, but passive acoustic monitoring has the added benefit of providing continuous data recording regardless of the time of day or weather conditions (Lammers & Munger, 2016). The vessel surveys in this study are intended to supplement the acoustic data with visual confirmation of species and behavior.

Spinner dolphins have three types of acoustic behavior: whistles, echolocation clicks, and "burst pulse" click trains. Frequency modulated, tonal whistles and "burst pulse" click trains are the main types of acoustic signals in social interactions (Lammers et al., 2006). Whistles have a fundamental frequency range of 2-22 kHz and are generally used for group coordination when the dolphin pod is spread out (Norris et al., 1994; Bazúa-Durán & Au, 2002). Echolocation clicks range between 2 and 200 kHz with an inter-click interval greater than 10 milliseconds and are primarily used as biosonar while foraging or navigating the environment (Au, 1993; Lammers et al., 2004). Burst pulse click trains and echolocation clicks have a similar frequency range, but burst pulse click trains have a smaller inter-click interval of 0.5-10 milliseconds (Lammers et al., 2004). Burst pulses are used by nearby dolphins to communicate (Lammers et al., 2004). When resting, spinner dolphins remain fairly silent but increase their acoustic activity while traveling or foraging. Therefore, the variation in timing and type of acoustic behavior can be used to determine the dolphins' presence in a given area and infer their social state (Heenehan et al., 2016a, 2016b).

Methods

Passive Acoustic Monitoring

Ecological Acoustic Recorders (EARs) are bottom-moored autonomous recorders programmed to provide long-term monitoring for the presence of spinner dolphins at regular intervals (Lammers et al., 2008a). EARs were deployed at nine locations: in Maui Nui along the west Maui coast at Honolua Bay, off Kahekili beach, north of the Mala boat ramp (North Mala), off Launiupoko beach park, and off Mile Marker 17 on the Honoapiʻilani highway (MM17); along Southeast Lānaʻi at Mānele Bay and off Lōpā beach; in the Maui-Lānaʻi channel, also known as the ʻAuʻau channel; and in an established resting bay off the Waiʻanae coast of Oʻahu known as Mākua (Figure 1). The Mākua Beach location on Oʻahu was selected to represent the bioacoustic activity pattern that can be expected to be present in a spinner dolphin resting bay.

Each EAR was set to record at a sample rate of 64 kHz on a 10% duty cycle of 30 seconds every 300 seconds producing recordings with an effective bandwidth of 0-32 kHz. This frequency range is sufficient to capture the fundamental frequencies of spinner dolphin whistles and the lower end of the frequency range of click trains (Au, 1993). The detection radii of the Kahekili, Launiupoko, Maui-Lānaʻi, MM17, and North Mala summer deployments were estimated with a series of pinger tests (Appendix B). EARs in relatively shallow water

(~12-20 m) were diver-deployed and moored with a 60-lb concrete block set on the sandy substrate by certified scientific scuba divers. These included the Mākua, Honolua, Kahekili, and MM17 EARs. The other EARs were deployed in deeper waters (~30-70 m) and were each anchored by 125 lbs of sand bags connected to the EAR, which was coupled with paired SubSeaSonic AR-60 acoustic releases to execute the recovery.

The EARs recorded for at least two months. The North Mala, Maui-Lāna‘i, and Launiupoko EARs were deployed in late June 2016 and recovered in late September 2016. The Kahekili and MM17 EARs were deployed in June 2016 and recovered in December 2016. The Lōpā and Mānele EARs were deployed from late September 2016 to the beginning of December 2016. The Honolua EAR was deployed in October 2016 and was recovered in mid-December 2016, while the Mākua EAR was deployed at the end of September 2016 and was recovered in February 2017. In addition, archived data from winter deployments at the Maui-Lāna‘i (mid-January 2015 to mid-March 2015), Kahekili (mid-January 2016 to mid-March 2016), and MM17 (mid-January 2016 to mid-March 2016) EAR sites made during a previous project were analyzed to detect any seasonal patterns in spinner dolphin acoustic activity. The Maui-Lāna‘i deployment had a sample rate of 125 kHz with an effective bandwidth of 0-62.5 kHz, and the Kahekili and MM17 deployments had sample rates of 50 kHz with effective bandwidths of 0-25 kHz. See Table 1 for deployment specifications.

Analysis of Acoustic Recordings

EAR recordings were converted from .BIN format files to .ewav files using a custom script in *MATLAB* (The Mathworks Inc., Natick MA; Version 2015b). The recordings were then visually scanned in the *MATLAB* program *Triton* (Wiggins, 2003) using an FFT length of 1400 points, with 50% overlap, and a plot length of 15 seconds. For each recording containing dolphin signals, dolphin acoustic activity was quantified using an Acoustic Activity Index (AAI) based on the quantity of whistles, clicks, and burst pulses present (Table 2). The resulting data were compiled to establish the average acoustic activity index for each hour of the day for every day of every deployment. In order to characterize the ambient noise of each EAR location, root mean square sound pressure level (RMS SPL) was calculated for each deployment in 1-octave frequency bands and plotted by date and hour of the day (Appendix A). The frequency ranges of each octave band in the RMS SPL plots vary depending on the sampling rate of the deployment. All dB are re 1 µPa.

In order to test the significance of deployment (site and season) and time of day as predictors of variation in spinner dolphin acoustic activity, a generalized additive model (GAM) with a beta regression distribution was fitted to the data. This model was selected because the distribution of AAI is nonparametric, positive, and bounded. The statistical tests were performed in the software package *R* with *base, lmtest, dplyr, car, MuMIn, mgcv, StreamMetabolism, tidyr, ggplot2,* and *colorspace* packages (Zeileis & Hothron, 2002; Wickham, 2009; Fox & Weisberg, 2011; Wood, 2011; R Core Team, 2015; Wickham & Francois, 2015; Barton, 2016; Ihaka et al., 2016; Sefick Jr., 2016; Wickham & Henry, 2018).

Deployment was tested as a variable for acoustic activity because it was expected that spinner dolphins utilize certain areas in various seasons differently than others in their daily behavioral cycles and as a result, different deployments would have varying acoustic patterns. Time of day was binned into three categories for analysis in order to reduce temporal autocorrelation within the data. The hours between local sunrise and noon (1200 h) were defined as “Sunrise-Noon” in order to characterize the acoustic activity of spinner dolphins during the hours in which they typically are traveling from foraging grounds to the nearshore resting bays and beginning their resting behaviors. The hours between noon and local sunset were defined as "Noon-Sunset" to characterize the acoustic activity of spinner dolphins during the hours in which they transition from resting to traveling offshore to foraging grounds. The final category, "Night" was defined as the hours between sunset and sunrise, when dolphins exhibit foraging behavior (Norris et al., 1994; Tyne et al., 2015).

Vessel Surveys

Concurrent with the EAR deployments, vessel surveys and focal follows were used to provide additional detail about the spinner dolphins' movements and behavioral state at different locations in Maui Nui. An initial series of seven surveys were conducted over a two-week period in August 2016 that covered the west Maui coast and offshore waters where spinner dolphins have been reported. The survey tracks closely followed the location of the EAR deployments in order to confirm spinner dolphin presence. Each survey began out of Lāhainā Harbor in a 21-ft cuddy cabin vessel with two observers on board cruising at 10 knots. When animals were encountered and conditions permitted, spinner dolphin groups were followed for as long as feasible with the ultimate goal of observing the group through their resting period and tracking them to their foraging area in the late afternoon and early evening. As the dolphins were tracked, their group size, location, and behavior were recorded every 15 minutes using an established ethogram of typical behaviors (Lammers et al., 2004). Three additional vessel surveys took place in June of 2017.

Results

Passive Acoustic Monitoring

A total of 191,808 recordings were manually scanned for dolphin acoustic signals, and assigned a value for the AAI. The average AAI was plotted by each deployment in Figure 2, and by hour of day for each deployment in Figure 3 to illustrate the diel patterns that occur within each 24-hour day. Average AAI for each time of day category within each deployment were compared in Figure 4. RMS SPL plotted against the hour of day and date for each deployment can be found in Appendix A. All deployments detected snapping shrimp chorusing as indicated by the peaks in RMS SPL between 0500 to 0700 h and 1800 to 2000 h (Figure A1-A12; Kaplan et al., 2017).

Mākua – fall

The deployment off of Mākua Beach on Oʻahu represents a well-established spinner dolphin resting bay. Therefore, the average AAI and diel patterns in acoustic activity provide a baseline with which to compare data collected from all other deployments. The Mākua deployment had the greatest acoustic activity of all deployments with an average hourly AAI of 0.181 ± 0.011 (Figure 2). This higher average is also apparent in the diel trends shown in Figure 3. Average hourly AAI was greatest at Mākua from 0600 to 1600 h with a peak of 0.635 at 0800 h and a second peak of 0.249 at 1500 h. Acoustic activity persisted during the nighttime hours, but at lower levels with the highest average of 0.051 occurring from 2000 to 2100 h.

In the Mākua soundscape—based on the RMS SPL calculations— the fullband frequencies had an average SPL between 107 and 109 dB (Figure A1-a). Low frequencies between 0 and 1.56 kHz fluctuated around 95 dB, peaking at 97 dB between 0600 and 1800 h. The range of frequencies in which dolphin signals occur, 1.56-25 kHz, had SPLs between 94 and 108 dB (Figure A1-b).

Honolua – fall

The average hourly AAI in Honolua Bay was 0.049 ± 0.006 (Figure 2). Diel patterns also revealed greater average AAI during daytime hours than nighttime hours (Figure 3). Hourly average AAI had a maximum of 0.194 at 0800 h and a small secondary peak of 0.054 at 1400 h. RMS SPL of the ambient noise in Honolua Bay ranged between 110 and 112 dB in the fullband frequencies. Low frequencies of 0-2 kHz ranged between 95 and 102 dB. The octave bands that include dolphin signals (2-32 kHz) ranged from 100 to 108 dB (Figure A2-a). A slight increase in the lowest octave band of approximately 1 dB occurred between 1000 and 1500 h (Figure A2-b).

Kahekili – summer

The average AAI for recordings in the Kahekili summer deployment by day is 0.006 ± 0.001 (Figure 2). The highest AAI averaged by hour was 0.024 at 1500 h (Figure 3). The 0-2 kHz octave band RMS SPL varied between 100 and 102 dB, while the octave bands between 2 and 32 kHz varied between 100 and 108 dB, and the fullband varied between 112 and 113 dB (Figure A3-a). The peaks indicating snapping shrimp chorus were most notable in the 0-2 kHz octave band. This low frequency band was also the only octave band to show a greater SPL during the daytime hours than in the nighttime hours (Figure A3-b).

Kahekili – winter

The winter deployment in Kahekili had less acoustic activity than the summer deployment with an average AAI of 0.001 ± 0.001 (Figure 2). The greatest AAI averaged by hour was 0.012 at 1500 h (Figure 3). The RMS SPL of the fullband frequencies varied between 113 and 118 dB. Frequencies between 1.56 and 25 kHz ranged between 99 and 116 dB, and the low frequency octave band of 0-1.56 kHz ranged between 111 and 116 dB (Figure A4-a). The average SPL of the lowest frequency octave band was greater than any of the other individual octave bands (Figure A4-b). This was likely due to the presence of humpback whale song during the humpback whale breeding season (Au et al., 2000).

Launiupoko – summer

The Launiupoko deployment had an average AAI of 0.018 ± 0.002 (Figure 2). The greatest AAI averaged by hour was 0.040 at 1200 h (Figure 3). The fullband RMS SPL ranged between 105 and 109 dB, the 0-2 kHz octave band ranged between 95 and 101 dB, and the octave bands ranging from 2 to 32 kHz varied between 91 and 104 dB (Figure A5-a). In this deployment the RMS SPL was greater during the daytime hours between 0600 and 1900 h than the nighttime hours. The most notable increase within this timeframe was approximately 4 dB in the 0-2 kHz and 2-4 kHz octave bands (Figure A5-b).

Lōpā – fall

The average AAI for the deployment off of Lōpā was 0.005 ± 0.001 (Figure 2). The hour with the greatest average AAI was 1100 h with a value of 0.026 (Figure 3). In the Lōpā deployment the RMS SPL of the fullband frequencies fell between 108 and 111 dB (Figure A6-a). The 0-2 kHz octave band had RMS SPLs between 95 and 107 dB, and the octave bands between 2-32 kHz varied between 95 and 104 dB, with the 4-32 kHz ranging between 102 and 104 dB. The RMS SPL of the 0-2 kHz octave band had a peak at 101 dB around 0800 h that was not reflected in the other frequencies (Figure A6-b).

Mānele – fall

Of the Maui Nui EARs, the Mānele Bay deployment had the greatest average AAI of 0.073 ± 0.008 (Figure 2). When averaged by hour of day, AAI was greater between 0700 and 1600 h than during the nighttime hours, and the greatest AAI of 0.232 occurred at 1200 h (Figure 3). A second peak of 0.180 occurred at 1500 h. The RMS SPL of the fullband frequencies had little fluctuation over the duration of the deployment with a range between 113 and 114 dB (Figure A7-a). The 0-2 kHz octave band ranged between 98 and 100 dB, while the 2-32 kHz frequencies fell between 102 and 110 dB. Diel patterns in the RMS SPL of the 0-2 kHz octave band show a 3 dB increase during the daytime hours with a peak of 101 dB at 1000 h (Figure A7-b). Vessel traffic may have caused the increase in low frequency noise during the day.

Maui-Lāna'i – summer

The summer deployment at the Maui-Lāna'i location had an average AAI of 0.045 ± 0.005 (Figure 2). The diel averages indicate that acoustic activity occurs at night in this location with the highest nighttime hourly average of 0.047 occurring at 0300 h. The acoustic activity is greater during the day; the highest average AAI occurs at 0900 h with a value of 0.103 (Figure 3). A second peak occurs at 1500 h with a value of 0.097.

The Maui-Lāna‘i summer deployment had one of the quieter soundscapes with a fullband RMS SPL fluctuating between 103 and 106 dB (Figure A8-a). Low frequencies of 0-2 kHz as well as the frequencies from 2 to 32 kHz ranged from 93 to 100 dB. Frequencies ranging between 0 and 8 kHz showed a 3-5 dB increase in RMS SPL between the hours of 0600 and 1600 h (Figure A8-b).

Maui-Lāna‘i – winter

The Maui-Lāna‘i winter dataset had high levels of ambient snapping shrimp broadband acoustics that distorted the upper frequency range, thus only whistles were detected. The average AAI was 0.013 ± 0.002, much lower than the average from the summer deployment in the same location (Figure 2). Average AAI was greatest at 0800 h with an average value of 0.031 (Figure 3). This deployment had one of the louder soundscapes with its fullband RMS SPL ranging between 110 and 116 dB (Figure A9-a). Octave bands from 3.9 to 62.5 kHz varied between 93 and 99 dB, while the 0-3.91 kHz octave band was 109-116 dB (Figure A9-b). As seen in the winter deployment of the Kahekili EAR, these higher RMS SPLs particularly in the lower frequencies correlate with the presence of humpback whale song.

MM17 – summer

Average AAI of the MM17 summer deployment was 0.015 ± 0.002 (Figure 2). When averaged by hour of day, 0000 h had the greatest AAI of 0.038 (Figure 3). The RMS SPL of the fullband frequencies was 105-106 dB indicating that this deployment was relatively quieter than the others (Figure A10-a). The 0-2 kHz octave band had RMS SPL’s from 96 to 98 dB, and the 2-32 kHz octave bands were 93-103 dB. RMS SPL varied only by approximately 1 dB when averaged by hour of day (Figure A10-b).

MM17 – winter

The winter deployment at MM17 had lower levels of dolphin acoustic activity than its summer counterpart with an average of 0.004 ± 0.001 (Figure 2). The greatest average AAI by hour occurred at 1900 h with a value of 0.013 (Figure 3). The RMS SPL's were greater in this deployment than those of the summer deployment. The fullband frequencies averaged between 109 and 117 dB (Figure A11-a). The frequencies from 1.56 to 25 kHz were 93-103 dB, while the low frequency band from 0 to 1.56 kHz had higher SPLs from 107 to 117 dB. The higher RMS SPL of lower frequencies in this deployment correlates with the presence of humpback whale song. Apart from the peaks in RMS SPL due to snapping shrimp, there were no diel patterns (Figure A11-b).

North Mala – summer

The North Mala deployment had an average hourly AAI of 0.027 ± 0.003 (Figure 2). The greatest hourly average of AAI was 0.117 at 1300 h (Figure 3). Nighttime acoustic activity had two peaks in the average AAI of 0.042 at 2000 h and 0.030 at 0100 h. The RMS SPL of the fullband frequencies was 108-114 dB, the 0-2 kHz octave band varied between 96 and 106 dB, and the octave bands from 2 to 32 kHz were 96-109 dB (Figure A12-a). The North Mala deployment had the greatest difference in RMS SPL between nighttime hours and daytime hours with a 9 dB increase during daytime hours in the 0-2 kHz octave band (Figure A12-b).

Seasonal Patterns

For the locations in which deployments took place during different seasons, the average hourly AAI was plotted by hour of day and season. In the winter deployment, Kahekili had the greatest average AAI of 0.012 at 1500 h followed by 0.009 at 0900 h. The only other hours of the day with average AAI greater than zero were 0200, 0800, and 1600 to 1800 h (Figure 5). The summer deployment had the greatest average AAI of 0.024 at 1500 h followed by 0.021 at 1100 h and 0.019 at 0900 h. The hours of day in the summer deployment with average AAI greater than zero included 0700 to 1800 h and 2300 h (Figure 5).

MM17 had peaks of acoustic activity during the nighttime hours of 1900 to 0400 h which was apparent in both the winter and summer deployments. In the winter deployment, MM17 had the greatest average AAI of 0.013 at 1900 h followed by 0.012 at 0100 h. At 1000, 1200, 1300, and 1600 h the average AAI was zero. In the summer deployment MM17 had a greatest average AAI of 0.038 at 0000 h. Each hour of day had an average AAI greater than 0.002, and a mid-day peak in average AAI of 0.024 and 0.022 occurred at 1000 and 1200 h respectively (Figure 6).

The winter deployment of the Maui-Lāna‘i EAR location had the greatest average AAI at 0800 and 1100 h with a value of 0.031. There was no hour of day with an average AAI of zero, but the AAI dipped down to approximately 0.002 at 1300 and 2200 h. The summer deployment in Maui-Lāna‘i had the highest average AAI at 0900 h of 0.103 with a secondary peak around 1500 h of 0.097. There were also elevated levels of average acoustic activity ranging between 0.036 and 0.047 during the nighttime hours of 0000 to 0400 h (Figure 7). In all three locations, the summer deployment had higher average AAI over more hours of the day than the winter deployment.

Generalized Additive Model

The following GAM was fit to the AAI, with the deployment (site and season), time of day, and a two-dimensional spatial smoother as predictors:

gam(BAAI ~ DayCat + Deployment + s(Longitude, Latitude, k = 10),

family = betar(link = “cloglog”)).

The term “BAAI” used in the GAM represents the AAI averaged by time of day category (Sunrise-Noon, Noon-Sunset, and Night) transformed so that $0 < BAAI < 1$ (Table 2). The range of AAI was adjusted to zero to one, and values exactly equal to zero or one were removed through the following formula:

$$BAAI = (AAI / 3.5 * (n - 1) + 0.5) / n,$$

where n = 2,178. This transformation was necessary because a beta distribution—which best describes the distribution of BAAI—assumes that no values are exactly equal to zero or one (Smithson & Verkuilen, 2006). The term “DayCat” indicates the category for the time of day previously defined as “Sunrise-Noon,” “Noon-Sunset,” and “Night.” A two-dimensional smoother for the interaction of Longitude and Latitude was included in the model to account for spatial autocorrelation.

The best fit models were determined using the *dredge* function in the MuMIn package to compare models of all possible combinations of the predictors (Barton, 2016). Model 8 was selected from the results as it included both predictors, DayCat and Deployment, the spatial smoother, and had the lowest corrected Akaike information criterion (Table 3). All three predictors were significant based on marginal F-tests: DayCat (chi-squared = 17.17, p-value = 0.000187), Deployment (chi-squared = 72.04, p-value = 6.06e-12), and the spatial smoother, s(Longitude, Latitude), (chi-squared = 93.96, p-value < 2.0e-16). Deployment explained 4.07%

of deviance, and DayCat explained 1.01% of deviance (Table 4). Fitted BAAI values predicted by the model were plotted against each predictor, time of day category and deployment, as well as the spatial smoother. The fitted BAAI values predicted by the GAM show that hours between sunrise and noon tend to have the greatest average BAAI, followed by hours between noon and sunset, while hours at night have the lowest (Figure 8). Hours in the Mākua deployment have the greatest predicted average BAAI, followed by the Maui-Lānaʻi summer deployment, Honolua Bay, Mānele Bay, and the Launiuopoko summer deployment. The deployments with the lowest predicted average AAI were the winter deployments in Kahekili and MM17 (Figure 9). The spatial smoother indicates an increase in BAAI at the coordinates of the Mākua EAR (Figure 10).

Honolua Bay vs Mānele Bay

Honolua Bay and Mānele Bay were two Maui Nui locations that stood out from the other deployments as having higher average AAI. Because these deployments were concurrent, it was possible to compare on an hourly basis, whether spinner dolphin signals were detected only in Honolua Bay, only in Mānele Bay, in both bays, or neither bay. At approximately 40 km distance from each other, it is unlikely that a spinner dolphin recorded in one bay will be recorded in the other bay within the same hour. Therefore, if dolphin signals are consistently seen in both bays simultaneously, then there is likely a group with some level of site fidelity to Lānaʻi, and another group with site fidelity to the west Maui coast. If dolphin signals are rarely seen in both bays simultaneously, it is more likely that one group of spinner dolphins varies spending time in either bay.

The percentage of hours in the deployments that included dolphin signals in Honolua Bay only, Mānele Bay only, both bays simultaneously, or neither bay were calculated (Figure 12). Of those deployments 47% of files did not contain dolphin signals in either location, 6% of files contained dolphin signals in both locations within the same hour of day, and 24% and 23% of files contained dolphin signals in only Honolua Bay and only Mānele Bay respectively. When plotted by the hour of day during which these detections occurred, dolphin signals were detected in both bays simultaneously between 0000 and 1400 h (Figure 13). Dolphin acoustic signals were detected during all hours of the day in Honolua Bay except for 1800 h. The most hours with only Honolua Bay detections occurred between 0600 and 0900 h. Hours with dolphin acoustic signals in Mānele Bay only were detected during all hours of the day except for 1800 h with a peak between 0700 and 1700 h (Figure 13).

Vessel Surveys

Out of ten surveys, six had successful spinner dolphin sightings (four from 2016 and two from 2017), of which five involved extended focal follows that allowed the tracking of animals (Figure 13). Generally, the spinner dolphin sightings first occurred in the late-morning before noon and continued into the afternoon. Dolphins were typically first seen along west Maui in the late-morning hours between 1100 and 1200 h and then followed into the Maui-Lānaʻi channel by early afternoon (Table 5). On two occasions the spinner dolphins were tracked as they moved toward the southeast side of Lānaʻi in the late afternoon, at which point the dolphins were steadily traveling towards Lānaʻi's south shore.

The first spinner dolphin sighting occurred on 2 August 2016 when a small group of four individuals was spotted at 0908 h along the west coast of Maui, just north of the North Mala EAR. The sighting was short and ended at 0923 h in roughly the same location. On 5 August 2016 a group estimated to be between 150-180 spinner dolphins was first located at 1218 h near the west Maui coast between the North Mala EAR and Lāhainā. The dolphins were seen milling and resting as they moved north towards Kāʻanapali, and then reversed to move down the coastline and into the ʻAuʻau channel past the Maui-Lānaʻi EAR. The sighting ended at 1649 h with the group moving eastward back into the channel.

On 10 August 2016 at 1132 h, an estimated 50 spinner dolphins were sighted north of the Kahekili EAR close to the Maui coastline. This group was followed into the middle of the ʻAuʻau channel where they were lost track of at 1403 h. The following day on 11 August 2016 approximately 80 spinner dolphins were spotted between the Kahekili and North Mala EARs at 1053 h. The group moved perpendicularly away from shore into the ʻAuʻau channel. By the end of the sighting at 1323 h, there were an estimated 50 individuals in the group being tracked.

Surveys continued the following summer during which, spinner dolphins were first sighted on 20 June 2017 at 1138 h. The group was composed of approximately 140 dolphins and were found between Lāhainā harbor and the Launiupoko EAR. The dolphins made their way across the ʻAuʻau channel towards the Lōpā EAR off the southeast side of Lānaʻi where the sighting was ended at 1553 h. By that time, the spinner dolphins had increased their aerial activities and were traveling southwest of Lānaʻi. The final dolphin sighting occurred on 21 June 2017 with approximately 140 individuals between the Lōpā and Maui-Lānaʻi EAR at 1217 h. This group changed their direction of travel between Maui and Lānaʻi four times before heading towards the Lōpā EAR at 1435 h and continuing in a southwestern direction.

Discussion

Spinner dolphin habitat-use patterns in Maui Nui do not follow the same patterns of site fidelity to specific bays that has been documented off the Kona coast of Hawaiʻi Island and the Waiʻanae coast of Oʻahu (Norris et al., 1994; Lammers et al., 2004; Thorne et al., 2012). Based on the combination of passive acoustic monitoring and vessel surveys, the evidence from this study suggests that spinner dolphins utilize the west Maui coastline, the southeast Lānaʻi coastline, and the ʻAuʻau channel during their daytime resting behaviors in Maui Nui. The Maui Nui monitoring sites could be distinguished from the Oʻahu sites by lower acoustic activity, and less defined bimodal diel patterns of acoustic activity.

Deployment (site and season) as well as the time of day in which an hour occurred whether it be from sunrise to noon, noon to sunset, or night, and a two-dimensional spatial smoother were significant predictors of the average acoustic activity index (BAAI). In other words, there were spatial, seasonal, and diel patterns in the acoustic activity of dolphins in Maui Nui and Mākua Beach. There is a clear distinction in the AAI between the Mākua site and the Maui Nui sites. More specifically, the deployment in Mākua, which was used as a baseline for spinner dolphin acoustic activity in a well-established resting bay, had the greatest average hourly acoustic activity index (AAI) of 0.181 ± 0.011. Honolua Bay and Mānele Bay were the two deployment locations in Maui Nui with the greatest average AAI of 0.049 ± 0.006 and 0.073 ± 0.008 respectively, which peaked between 0600 and 1300 h. The North Mala and Maui-Lānaʻi summer deployments also had AAI averages greater than the other Maui Nui EARs (0.027 ± 0.003 and 0.045 ± 0.005 respectively) with peak average AAI between 0800 and 1800 h (Figure 3). The Mākua deployment showed two peaks in activity, one at 0800 h and a second at 1500 h. The bimodal nature of dolphin acoustic activity illustrates the times during the day in which spinner dolphins enter or exit their rest behavior (Lammers et al., 2008b). This bimodal trend is also reflected in the Mānele Bay deployment and the Maui-Lānaʻi summer deployment, while the Honolua Bay deployment and North Mala deployment had only one peak in average AAI at 0800 and 1300 h respectively (Figure 3).

Acoustic activity during the nighttime hours, particularly in the Maui-Lānaʻi summer, MM17 summer, and North Mala summer deployments could suggest the presence of spinner dolphins at those times, however, it must be noted that there is a potential for the acoustic activity to be from a different odontocete species, such as the bottlenose dolphin (*Tursiops truncates*). Bottlenose dolphins follow different foraging and resting behavioral cycles than spinner dolphins, and therefore may be more likely to be active in those areas at night (Baird, 2016). Regardless of the dolphin species present, this increase in nighttime acoustic activity at these locations indicates an ecological shift at night (perhaps a behavioral change in a prey item).

The other Maui Nui deployments (Kahekili summer and winter, Launiupoko, Lōpā, Maui-Lānaʻi winter, and MM17 winter) all had average AAI below 0.018, but each contained dolphin acoustic activity to some degree (Figure 2). The sightings from the vessel surveys confirmed that spinner dolphins were found along the west Maui coast, southeast Lānaʻi coast, as well as the ʻAuʻau channel between Maui and Lānaʻi during daytime hours (Figure 13). Generally between 0900 and 1200 h spinner dolphins were sighted along the west Maui coast exhibiting resting behaviors and milling. Spinner dolphins were tracked into the ʻAuʻau channel around noon, where the sighting either ended or the group continued to move towards Lānaʻi (Table 5). These sightings support the idea that spinner dolphins in Maui Nui utilize both the coastline and the channel to rest rather than one specific bay as described for the Kona and Waiʻanae coasts (Norris et al., 1994; Lammers et al., 2004; Thorne et al., 2012).

Seasonal trends in average AAI were examined in the EAR locations where multiple deployments occurred: Kahekili, Maui-Lānaʻi, and MM17. All three locations had greater average AAI overall as well as by hour of day in the summer deployment than the winter deployments (Figure 2, 5-7). Winter deployments coincide with the humpback whale breeding season in Hawaiʻi. It is possible that spinner dolphins utilize other, less populated areas during this time, as they have been shown to do when exposed to increased human activity (Courbis & Timmel, 2009). Further exploration of seasonal trends in other Maui Nui locations, as well as studying the interactions between humpback whales and spinner dolphins would shed light on whether spinner dolphins do in fact, move to a new location to rest and/or reduce the acoustic signals they produce when humpback whales are present. Another possible explanation for seasonal trends in dolphin acoustic activity is seasonal change in prey distributions. Spinner dolphins have been shown to follow closely both the vertical and horizontal migrations of the mesopelagic boundary community (Benoit-Bird & Au, 2003). Therefore, changes in the spatial patterns of dolphin acoustic activity would likely mirror changes in the prey distribution.

The Honolua Bay and Mānele Bay deployments were among the sites with the highest levels of AAI. When compared by concurrent hours, these two deployments had dolphin acoustic activity in both bays within the same hour only 6% of the time (Figure 11). The hours in which dolphin acoustic activity was detected in either bay were split almost evenly between both locations. This suggests that rather than one Lānaʻi group of spinner dolphins and a separate group of west Maui spinner dolphins, there is likely one main group that occupies the area using both island coasts. The presence of dolphin acoustic detections in Honolua Bay (especially in the earlier morning hours of 0600 to 0800 h) is particularly interesting due to the distance from presumed foraging grounds west of Lānaʻi (Benoit-Bird & Au, 2003). With Mānele Bay's close proximity to this foraging area, it seems unlikely that spinner dolphins would select Honolua Bay approximately the same percentage of the time. Therefore, it is likely that dolphins are exploiting a food source in the Pailolo channel (between Maui and Moloka‘i) north of Honolua Bay. Acoustic data collected from an EAR for a previous project within the Pailolo channel contained echolocation clicks during the nighttime hours, suggesting that foraging by odontocetes does indeed occur in this area (Howe, 2016). Further research on the movement of the mesopelagic and epipelagic fish, squid, and shrimp community in the Pailolo channel could provide stronger evidence of whether or not spinner dolphins are utilizing a food resource in this area.

This study documents the ways in which spinner dolphins use the Maui Nui region for their daytime socializing and resting behavior. This analysis is timely as it provides a baseline of dolphin behavior and movement in the west Maui/Lāna’i area prior to the implementation of a new regulation that will limit the approach of humans to spinner dolphins to 50 yards with the potential for time-area closures (NOAA, 2016). The acoustic patterns described here can be compared to those collected in future deployments to reveal any changes in spinner dolphin habitat-use. Additionally, an understanding of the areas in Maui Nui that are frequented by spinner dolphins during their resting behaviors can inform resource managers which locations are particularly in need of protection. In the case of spinner dolphins in Maui Nui, dolphins move throughout the ‘Au‘au channel in addition to the coastlines of Maui and Lāna‘i, thus a time-area closure would not be practical or effective in providing protection. The application of the 50-yard approach limit would be a better option for the Maui Nui region as the closure of the entire channel is unrealistic. Time-area closures are a more viable option in areas where spinner dolphins exhibit the site fidelity to resting bays observed along the Kona and Wai‘anae coasts. This study demonstrates the necessity of establishing existing behavioral patterns of the species of interest before implementing management plans in a particular region in order to select the plan that will have the greatest likelihood of success.

Conclusion

The spinner dolphins in Maui Nui use the habitat during their daily behavioral cycles differently than has been described for spinner dolphins along the Kona coast of Hawaiʻi Island, and the Waiʻanae coast of Oʻahu (Norris et al., 1994; Lammers et al., 2004; Thorne et al., 2012). In particular, one main group of spinner dolphins moves between the west Maui coastline, southeast Lānaʼi coastline, as well as in the ʻAuʻau channel to rest. The middle of the ʻAuʻau channel does not fit the model of a shallow, sheltered resting bay with white sandy bottoms (Norris et al., 1994). It is possible that spinner dolphins are able to utilize the Maui Nui region almost as one large resting bay due to its uniquely shallow bathymetry between Maui, Molokaʻi, and Lānaʻi (Price & Elliot-Fisk, 2004). By using the channel as resting habitat, spinner dolphins may also be able to increase their distance from human disturbance that occurs along the coastline.

The habitat-use patterns of spinner dolphins in Maui Nui demonstrate that location must be taken into consideration when developing regulations for the management of spinner dolphins. The possibility of time-area closures proposed by the Pacific Islands Regional Office of NOAA Fisheries makes sense in the context of resting bays along the Kona coast of Hawaiʻi Island where spinner dolphin rest is closely associated with being inside a resting bay (Tyne et al., 2015). However, if applied to the Maui Nui area, the entire ʻAuʻau channel would need to be closed to human activity during the day—an unlikely prospect. The acoustic activity patterns of spinner dolphins in Maui Nui suggest that the 50-yard approach limit would be a more viable management option.

Figures and Tables

Table 1. EAR deployment specifications

EAR	Season	Start	End	Sample Rate (Hz)	Depth (m)	Latitude	Longitude
Honolua	Fall	10/5/2016	11/30/2016	64000	25.5	21.01693	-156.64980
Kahekili	Summer	6/30/2016	8/30/2016	64000	11.2	20.93892	-156.69470
Kahekili	Winter	1/15/2016	3/16/2016	50000	11.2	20.93892	-156.69470
Launiupoko	Summer	6/30/2016	8/20/2016	64000	43.9	20.84208	-156.66920
Lōpā	Fall	9/30/2016	11/30/2016	64000	42.2	20.80275	-156.79930
Mākua	Fall	10/1/2016	11/30/2016	50000	18.0	21.53210	-158.23450
Mānele	Fall	9/30/2016	11/30/2016	64000	20.9	20.73928	-156.88200
Maui-Lānaʻi	Summer	6/30/2016	8/30/2016	64000	70.1	20.84877	-156.74882
Maui-Lānaʻi	Winter	1/18/2015	3/18/2015	125000	70.1	20.84877	-156.74882
MM17	Summer	6/30/2016	8/30/2016	64000	12.0	20.83077	-156.64320
MM17	Winter	1/15/2016	3/16/2016	50000	12.0	20.83077	-156.64320
North Mala	Summer	6/30/2016	8/30/2016	64000	30.0	20.89812	-156.69720

Table 2. Acoustic Activity Index values for various categories of spinner dolphin signals. The index ranges from 0 to 3.5. Values increase with increasing acoustic activity. Beta distributions only include values greater than zero and less than one, therefore the AAI was divided by 3.5 and transformed—shown in the "Acoustic Activity Index Adjusted for Beta Regression" column (Smithson & Verkuilen, 2006).

Dolphin Signals in 30 s Recording	Acoustic Activity Index (AAI)	Acoustic Activity Index Adjusted for Beta Regression (BAAI)
No acoustic activity	0	0.00023
1-5 whistles	0.5	0.14316
Burst pulses only (<5 pulses)	0.5	0.14316
Sonar only <1/2 recording	0.5	0.14316
6-10 whistles	1	0.28610
Sonar only >1/2 recording	1	0.28610
Burst pulses only (>5 pulses)	1	0.28610
Sonar and burst pulses (<5 pulses)	1	0.28610
1-5 whistles and sonar or burst pulses	1.5	0.42903
>10 whistles	2	0.57097
Sonar and burst pulses (>5 pulses)	2	0.57097
1-5 whistles and sonar and burst pulses	2.5	0.71390
6-10 whistles and sonar or burst pulses	2.5	0.71390
6-10 whistles and sonar and burst pulses	3	0.85684
>10 whistles and sonar or burst pulses	3	0.85684
>10 whistles and sonar and burst pulses	3.5	0.99977

Table 3. *Dredge* output of best fit models based on corrected Akaike information criterion, inclusion of predictors in the model is indicated by a (+), and model 8 was selected for further interpretation

Model	Intercept	DayCat	Deployment	s(Lat, Lon)	R2	df	AICc
8	-3.998	+	+	+	0.1187	15	0.42
4	-4.036	+	+		0.1187	15	0.42
6	-4.203	+		+	0.1160	12	0.16

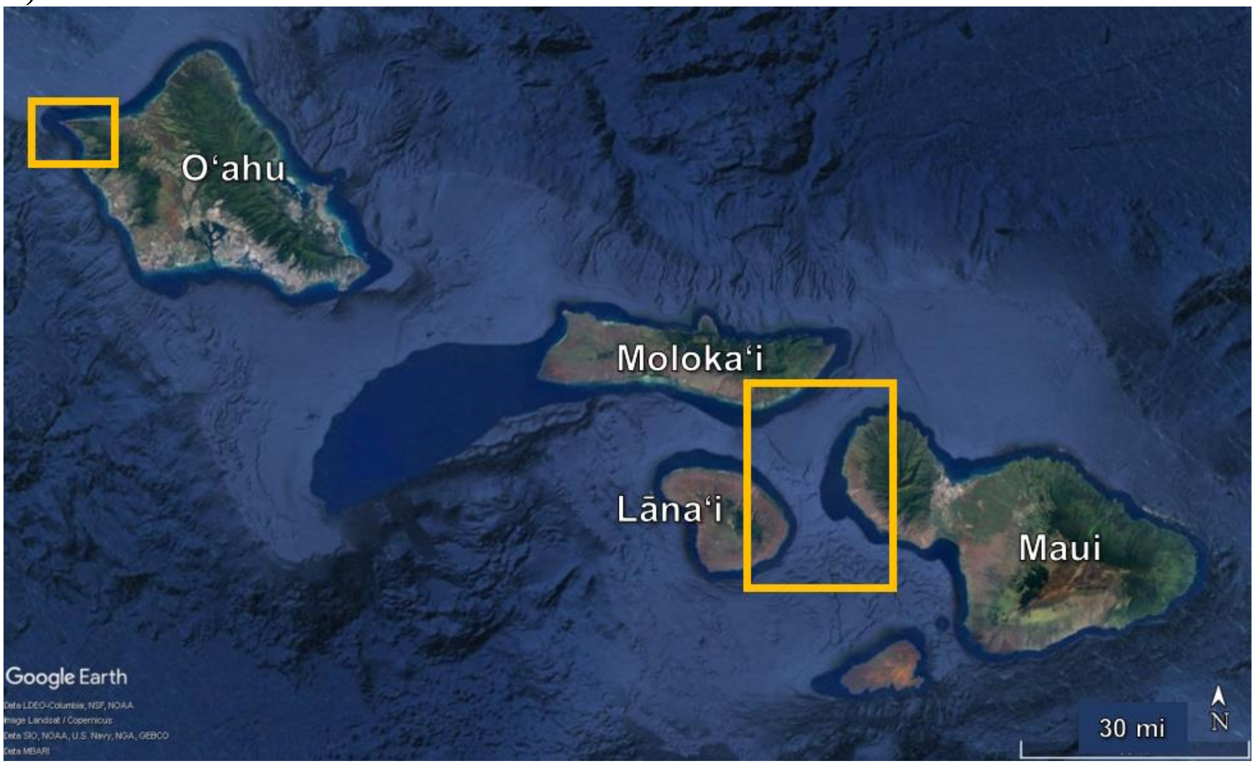
Table 4. Deviance explained by the GAM and each individual predictor

Predictor	Whole Model Total Deviance Explained	Deviance Explained without the predictor	Deviance Explained by the Predictor
Deployment	0.1665	0.1258	0.0407
DayCat	0.1665	0.1564	0.0101

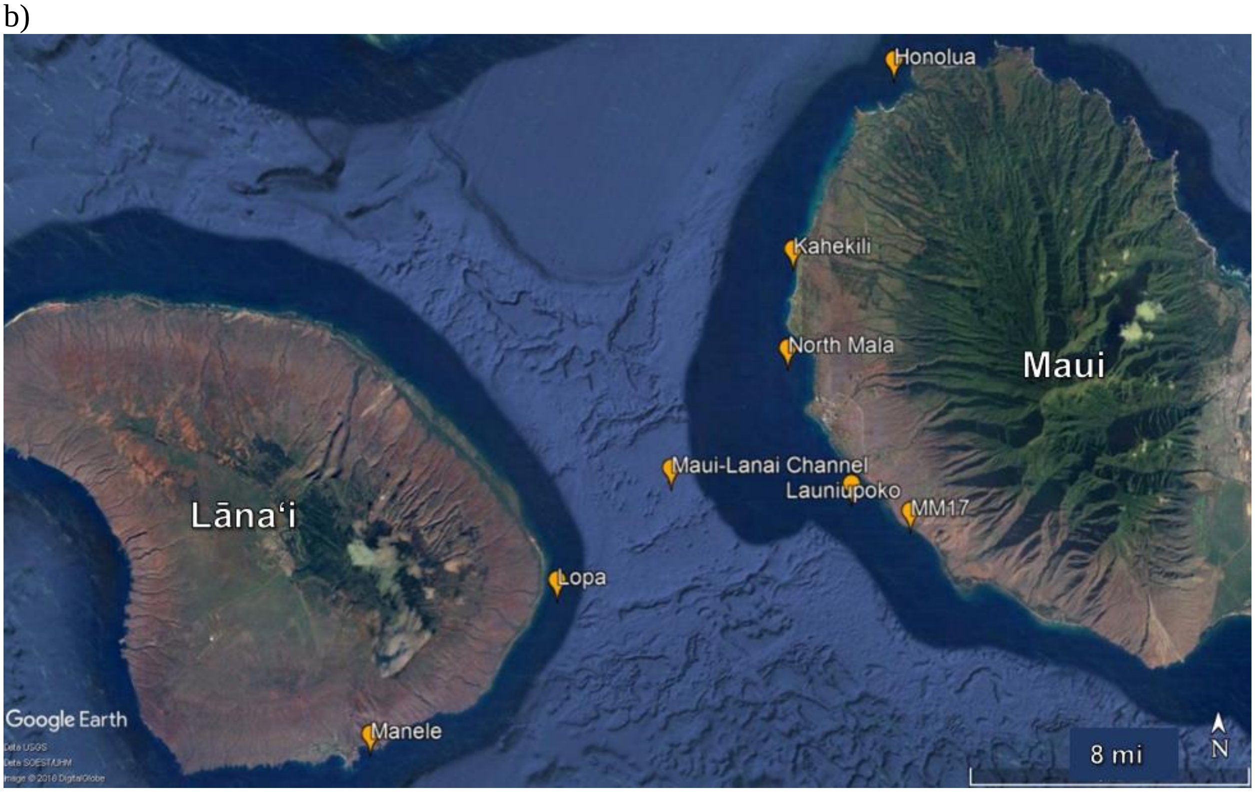
Table 5. Starting and ending times and locations for vessel surveys with dolphin sightings

Sighting Date	Start Time (h)	End Time (h)	Starting Location	Ending Location
8/2/2016	0908	0923	North Mala	North Mala
8/5/2016	1218	1649	North Mala	Lōpā
8/10/2016	1132	1403	Kahekili	Maui-Lānaʻi
8/11/2016	1053	1323	Kahekili	Maui-Lānaʻi
6/20/2017	1138	1541	Launiupoko	Lōpā
6/21/2017	1217	1436	Maui-Lānaʻi	Lōpā

a)


O'ahu
Moloka'i
Lāna'i
Maui
Google Earth
30 mi
N

b)


Honolua
Kahekili
North Mala
Maui
Maui-Lanai Channel
Launiupoko
MM17
Lāna'i
Lopa
Manele
Google Earth
8 mi
N

c)

Figure 1. Location of 2015 and 2016 EAR deployments generally as shown by the yellow boxes (a), and more specifically in Maui Nui (b), and O‘ahu (c). Map (a) ranges from -158.3962° to -155.8748° longitude and from 20.32903° to 21.78646° latitude. Map (b) ranges from -157.0149° to -156.4952° longitude and from 20.72011° to 21.02992° latitude. Map (c) ranges from -158.4103° to -157.5266° longitude and from 21.22212° to 21.71685° latitude.

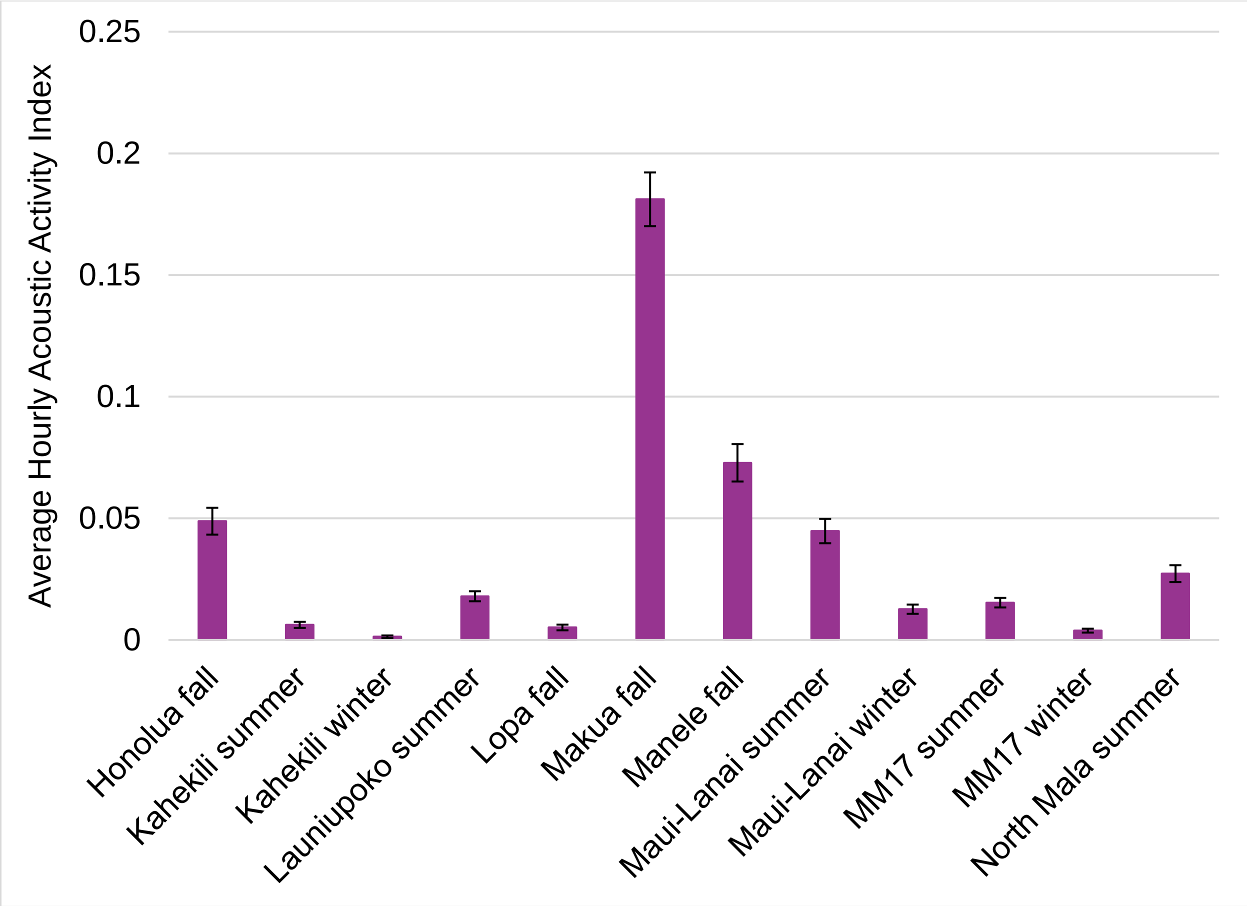


Figure 2. Average hourly AAI (± SEM) in each deployment. Deployments are denoted by location and season in which they took place.

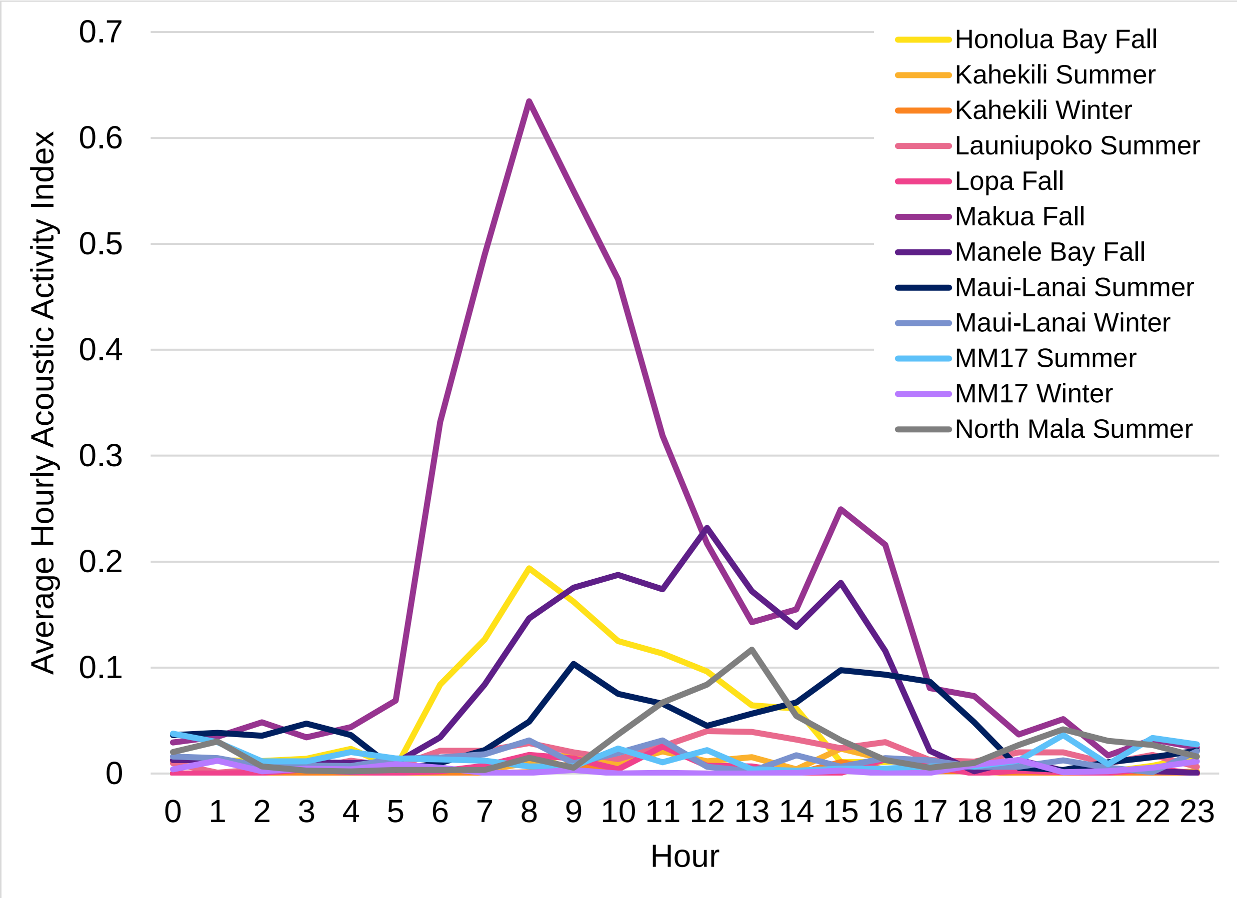


Figure 3. Average hourly AAI by hour of day for each deployment. Deployments are denoted by location and season in which they took place. In "Hour of Day," hour 0 begins at midnight, and hour 23 begins at 2300 h.

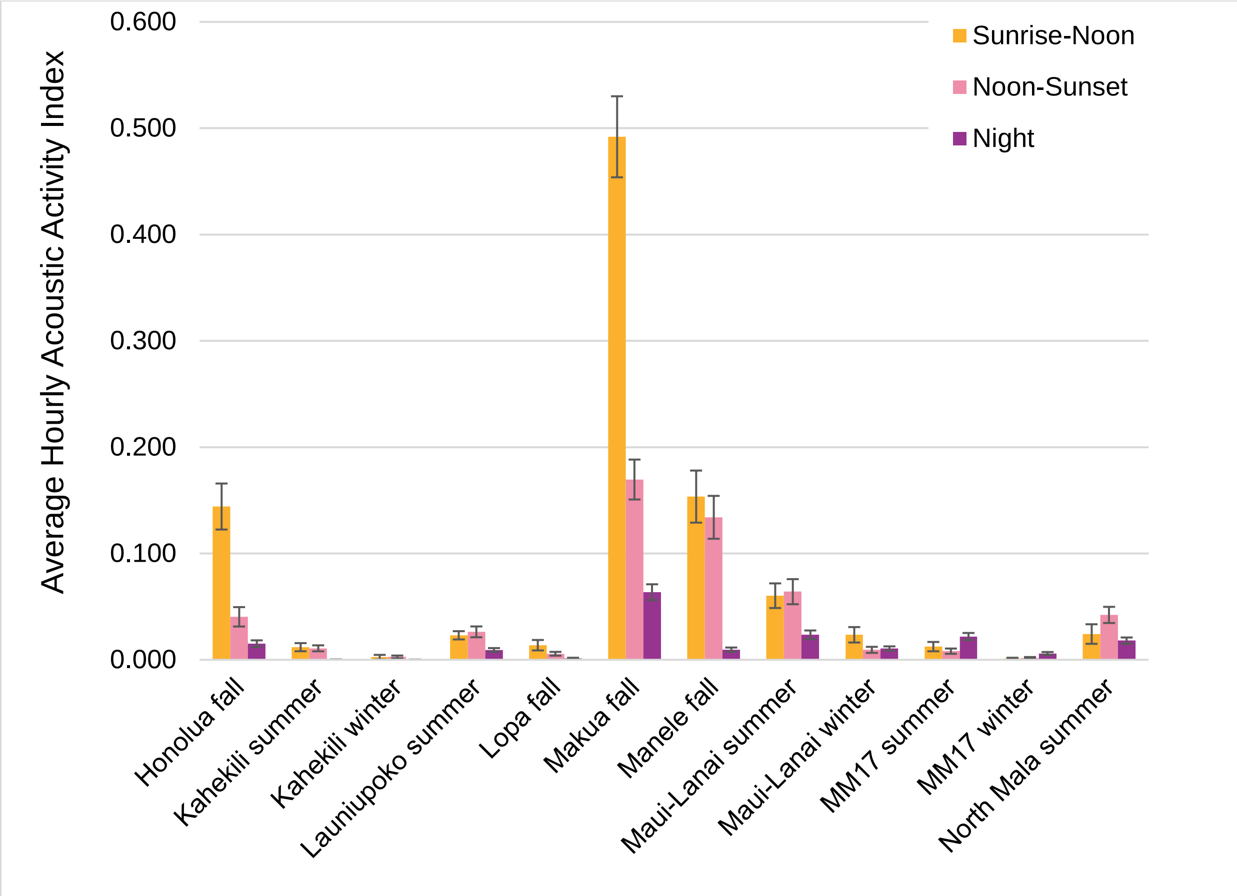


Figure 4. Average hourly AAI (±SEM) by time of day category and deployment. Deployments are denoted by location and season in which they took place. The “Sunrise-Noon” category includes hours between local sunrise and 1200 h, “Noon-Sunset” includes hours between 1200 h and local sunset, and “Night” includes hours between local sunset and local sunrise.

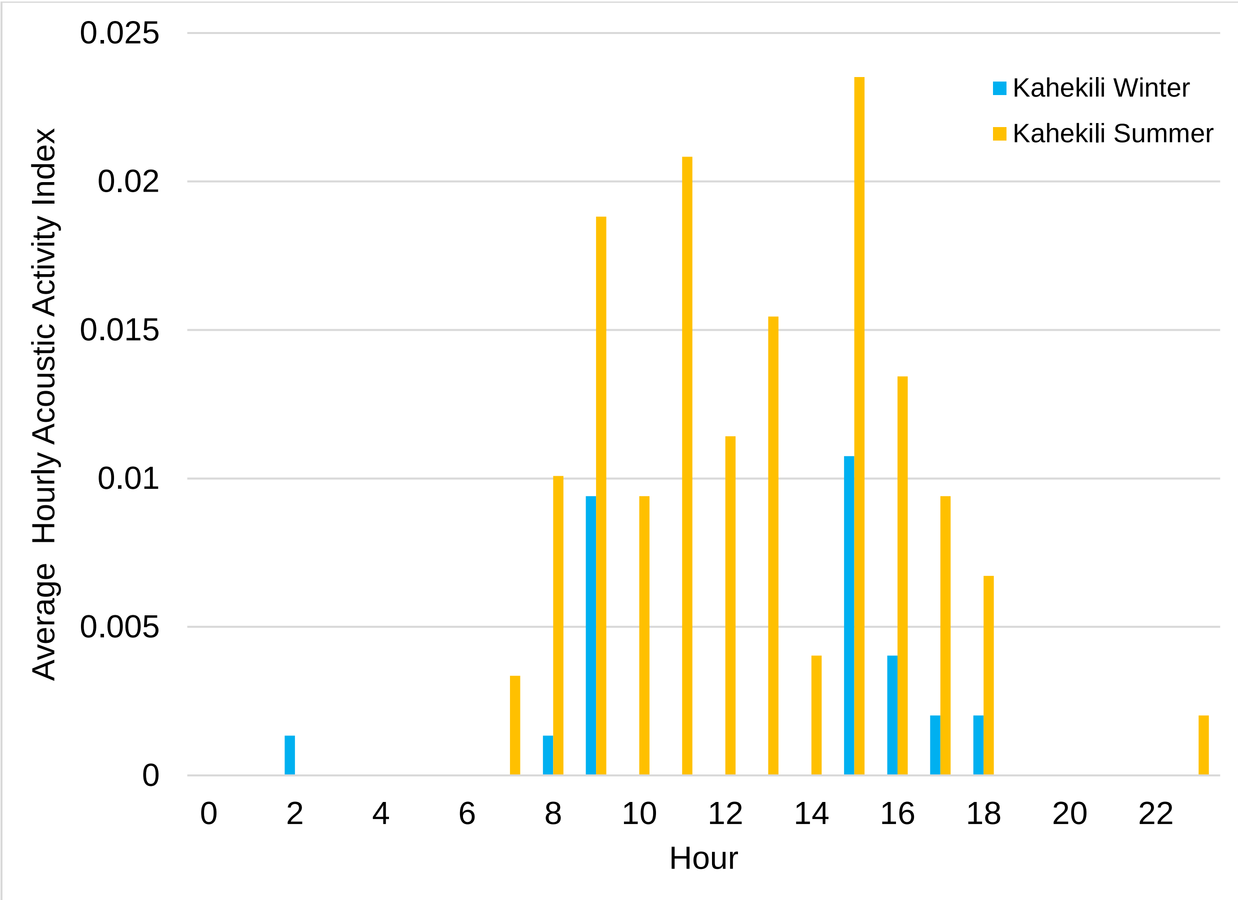


Figure 5. Average hourly AAI by hour of day for the winter deployment in Kahekili (15 January 2016 to 16 March 2016) and the summer deployment in Kahekili (30 June 2016 to 30 August 2016)

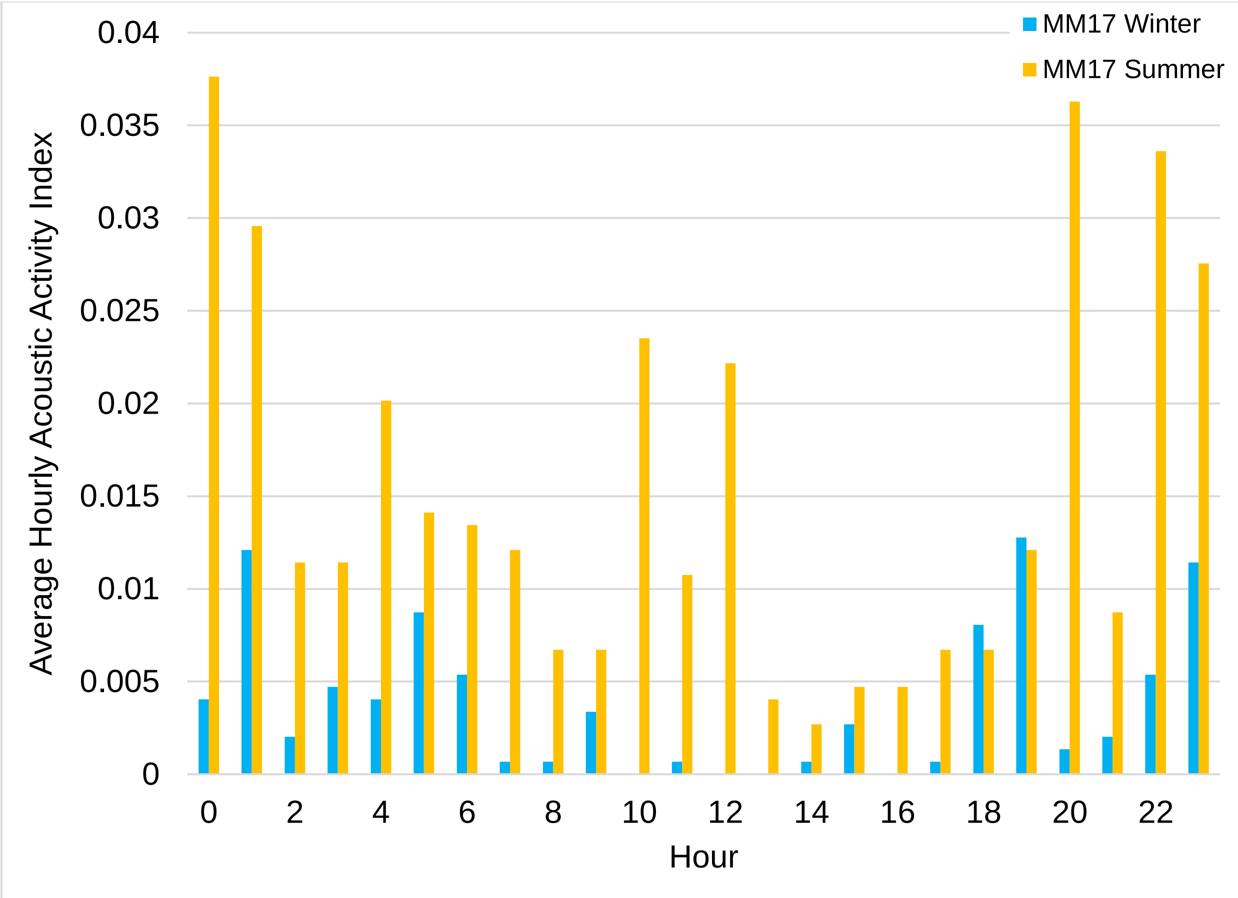


Figure 6. Average hourly AAI by hour of day for the winter deployment in MM17 (15 January 2016 to 16 March 2016) and the summer deployment in MM17 (30 June 2016 to 30 August 2016)

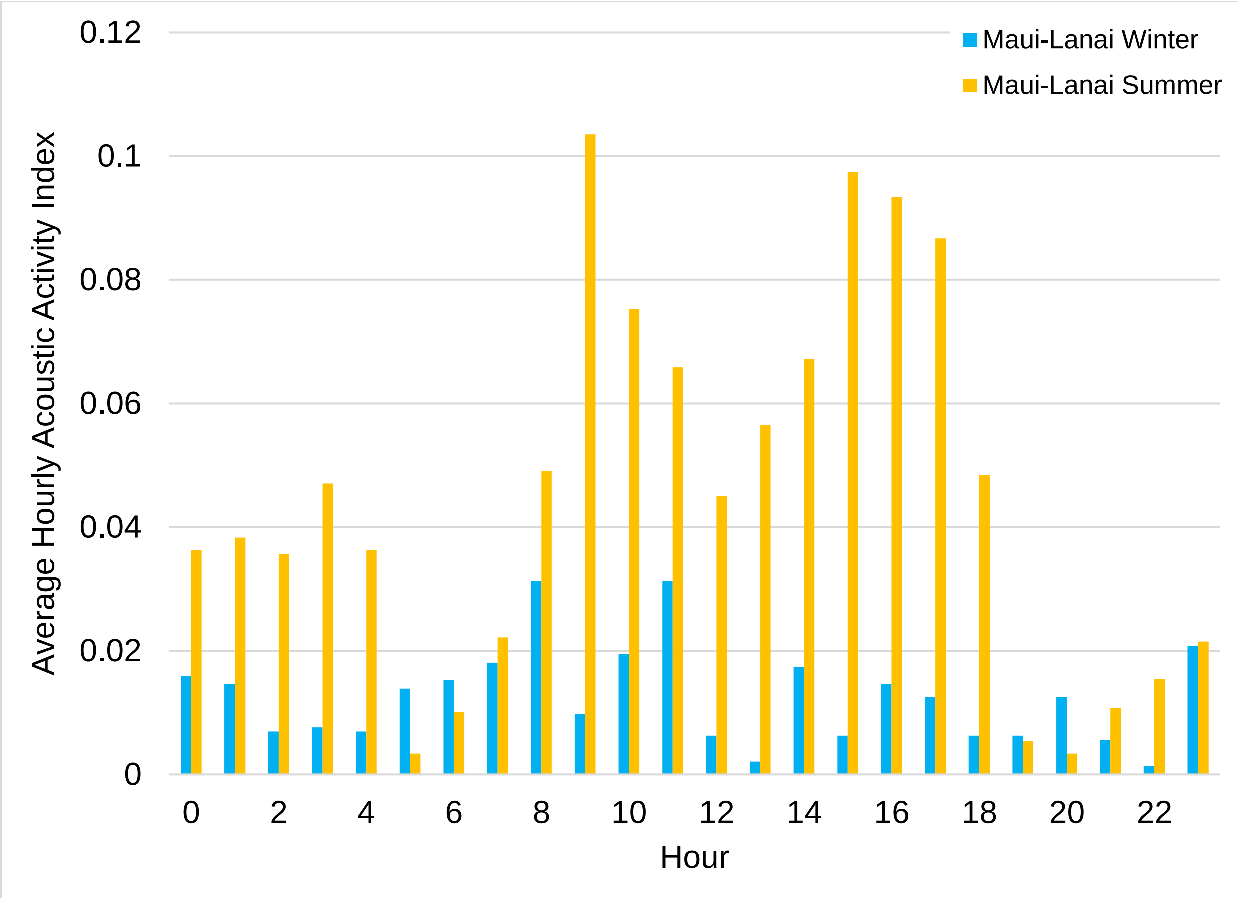


Figure 7. Average hourly AAI by hour of day for the winter deployment in Maui-Lānaʻi (18 January 2015 to 18 March 2015) and the summer deployment in Maui-Lānaʻi (30 June 2016 to 30 August 2016)

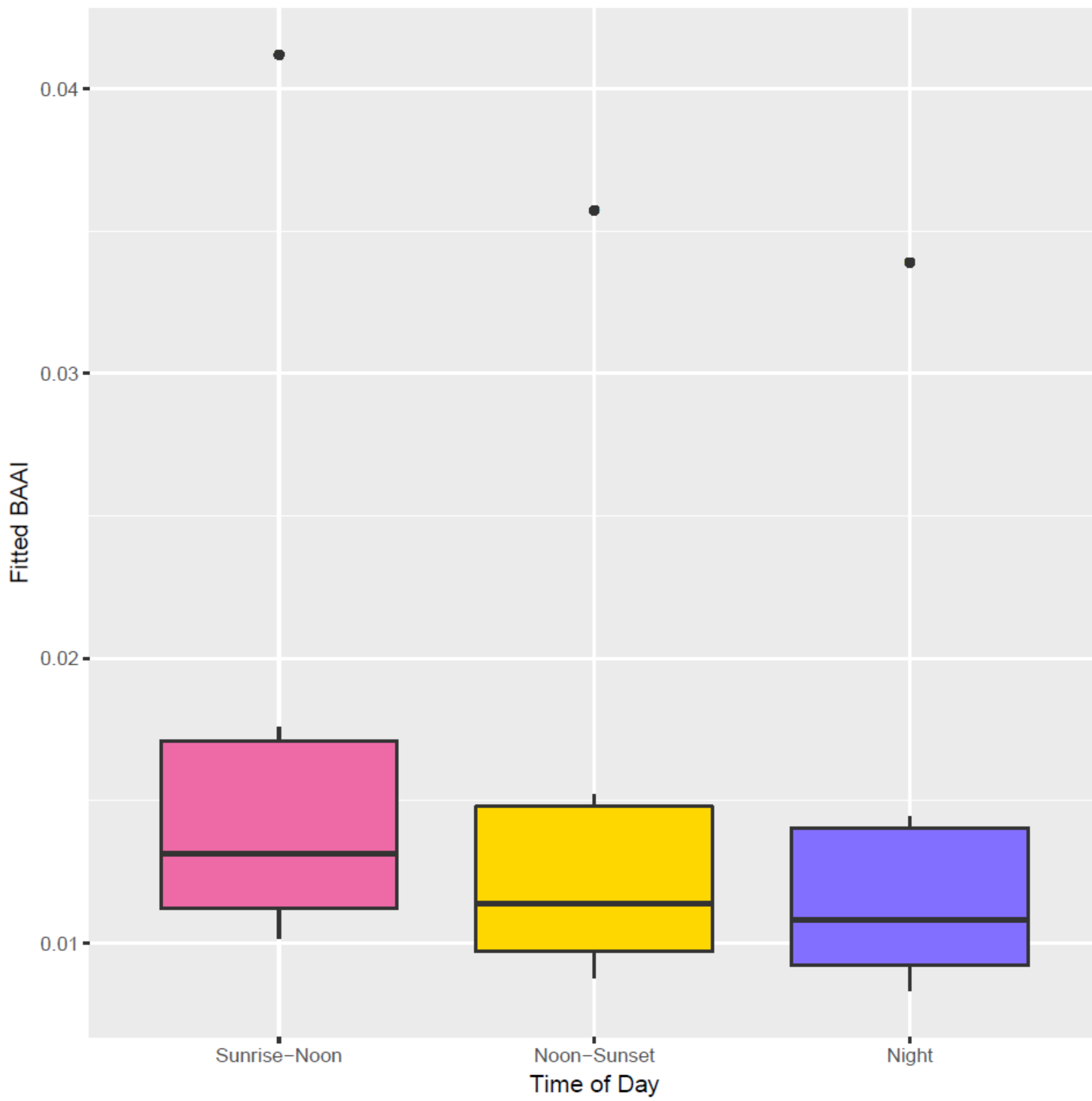


Figure 8. Fitted values of average acoustic activity index (BAAI, transformed for the beta regression) predicted from the GAM plotted against time of day categories

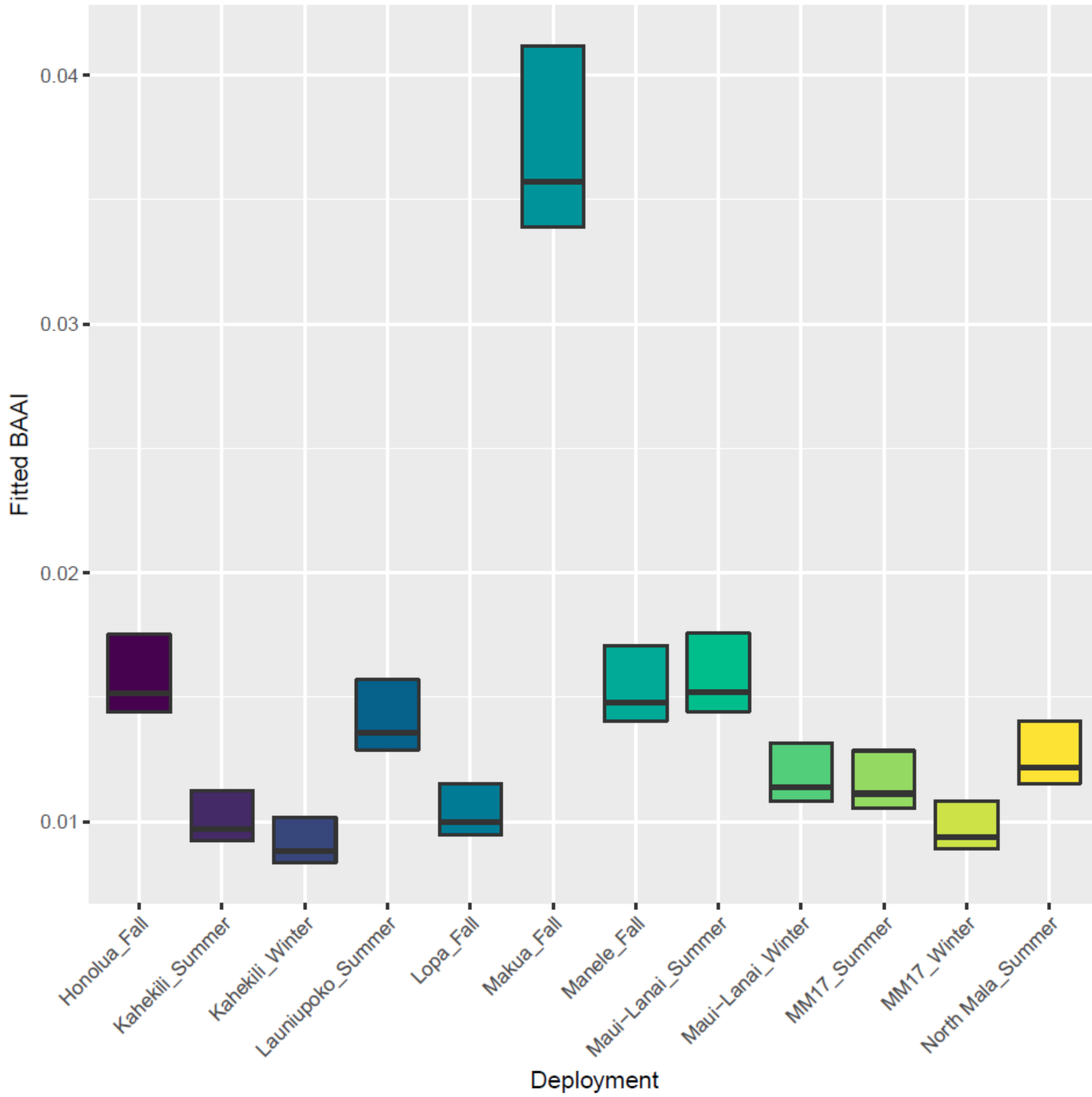


Figure 9. Fitted values of average acoustic activity index (BAAI, transformed for the beta regression) predicted from the GAM plotted against deployments. Each deployment is indicated by its name-based location and the season in which it took place.

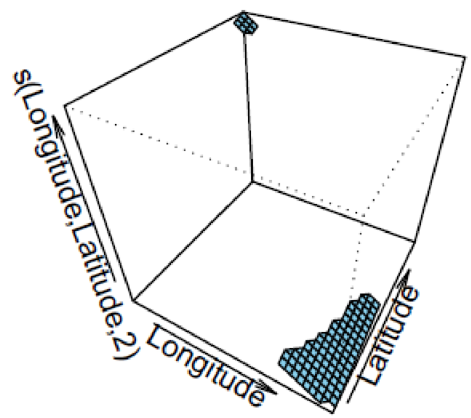


Figure 10. GAM smoother included in the model to account for spatial autocorrelation based on the interaction of Longitude and Latitude. The height of the light blue surface indicates BAAI for those coordinates.

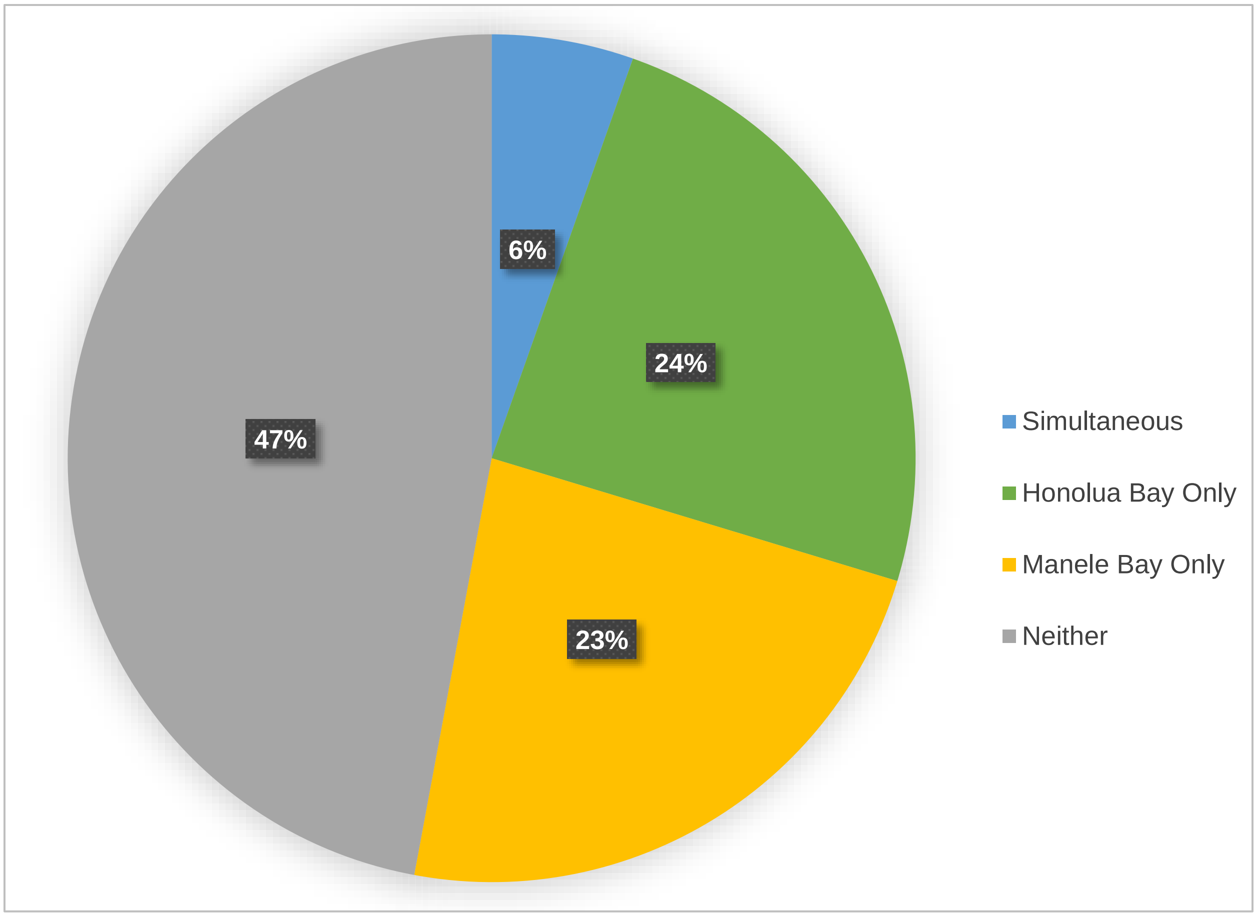


Figure 11. Percentage of hours from 5 October 2016 to 30 November 2016 with dolphin acoustic detections in both Honolua Bay and Mānele Bay simultaneously, only Honolua Bay, only Mānele Bay, or neither bay

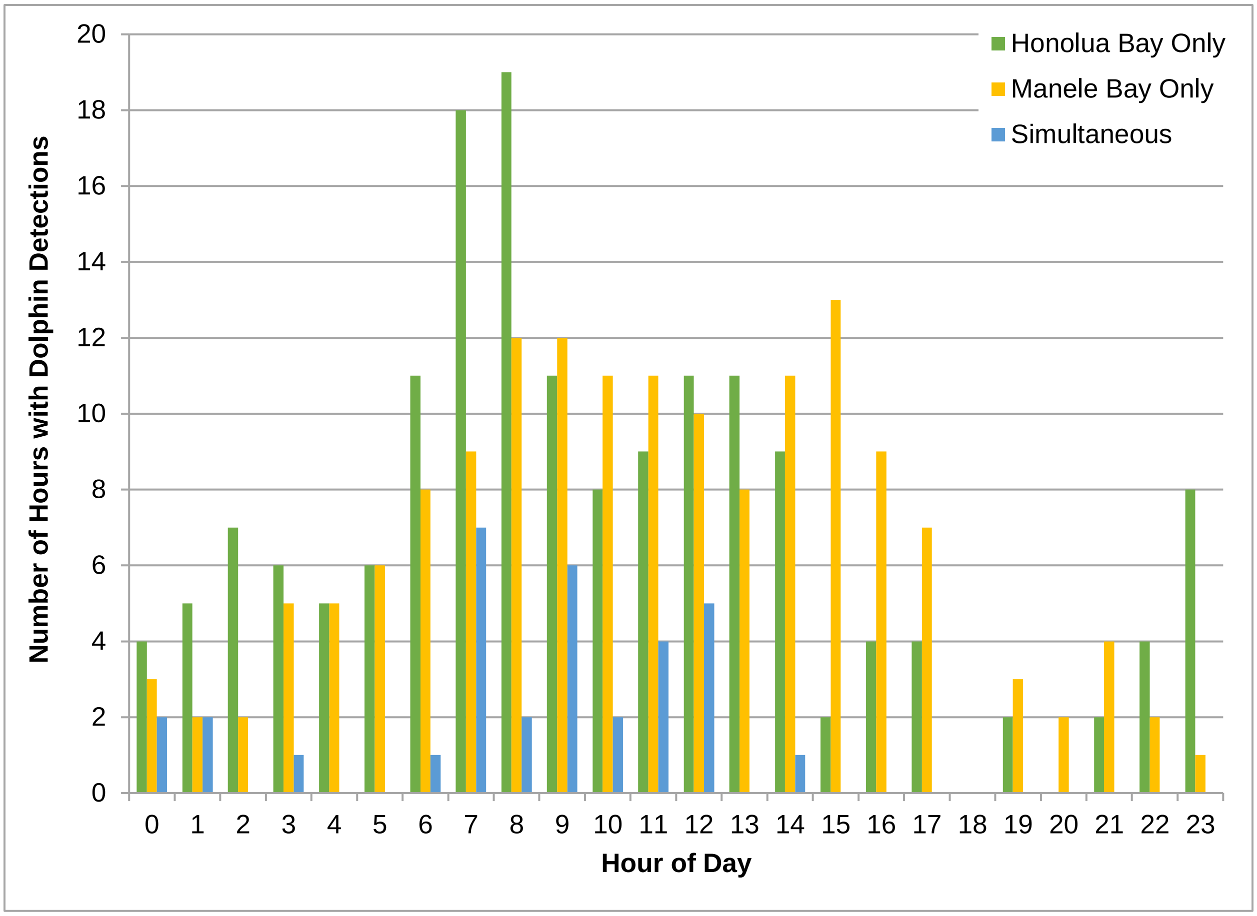


Figure 12. Number of files in which spinner dolphin detections occurred in Honolua Bay Only, Mānele Bay only, or both bays simultaneously by hour of day (where 0 represents midnight, and 23 represents 2300 h)

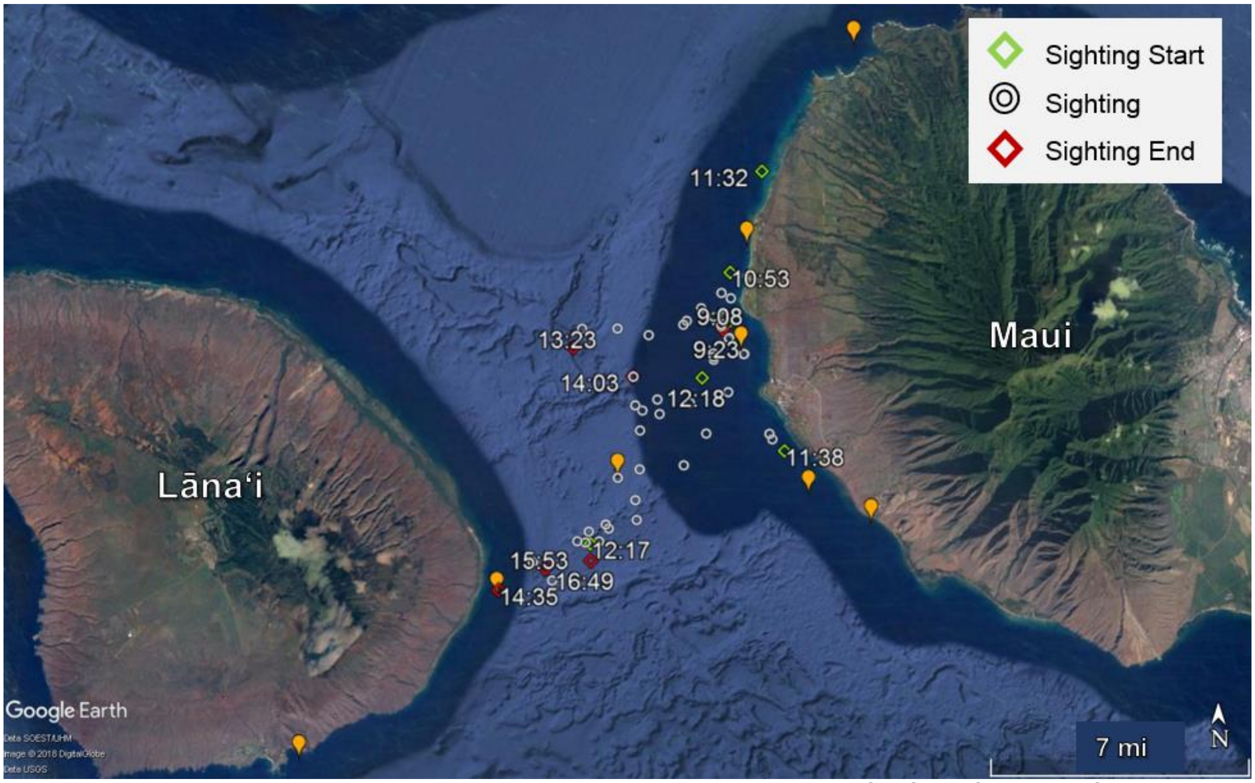
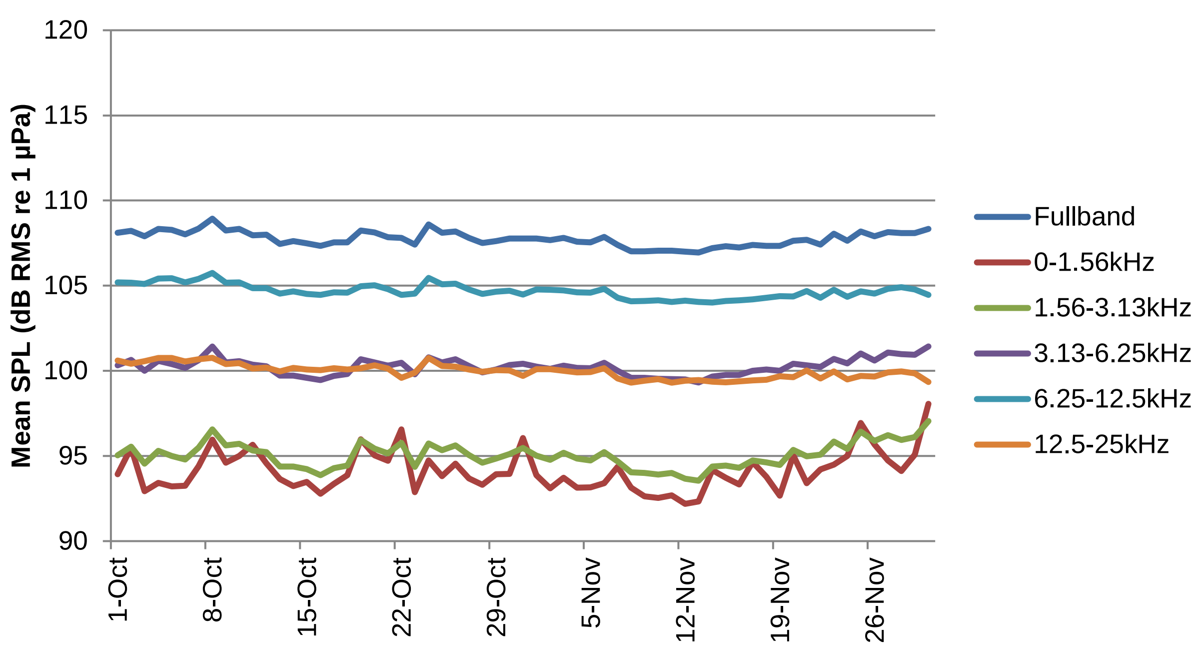


Figure 13. Spinner dolphin sightings from vessel surveys on the 2nd, 5th, 10th, and 11th of August 2016, and the 20th and 21st of June 2017. The beginnings and endings of sightings are labeled with the time at which they occurred. EAR locations are marked by orange labels. The longitudinal bounds of this map are -157.0098° to -156.4900°, and the latitudinal bounds are 20.7219° to 21.03114°.

Appendix A

Root Mean Square Sound Pressure Level

a)



b)

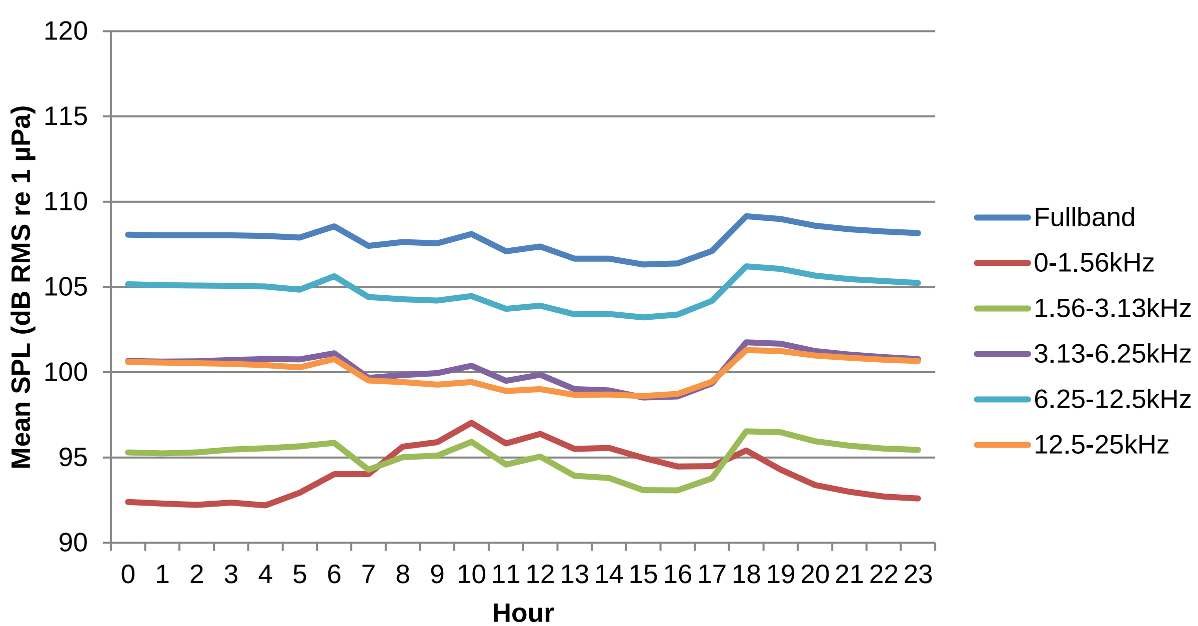


Figure A1. Mākua fall deployment root mean square sound pressure level in 1-octave frequency bands by date from 01 October 2016 to 30 November 2016 (a) and by hour of day from 0000 to 2300 h (b)

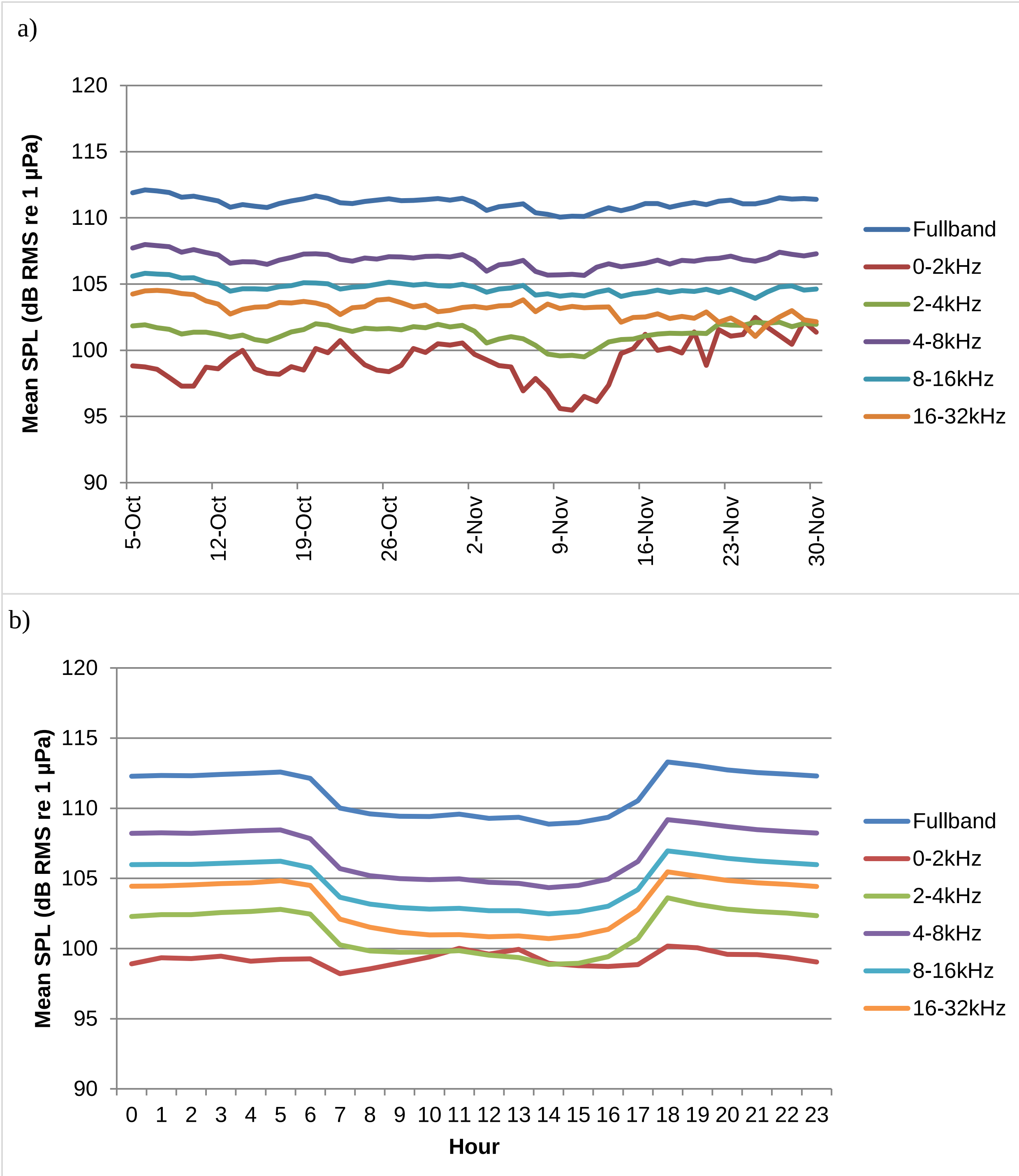


Figure A2. Honolua fall deployment root mean square sound pressure level in 1-octave frequency bands by date from 05 October 2016 to 30 November 2016 (a) and by hour of day from 0000 to 2300 h (b)

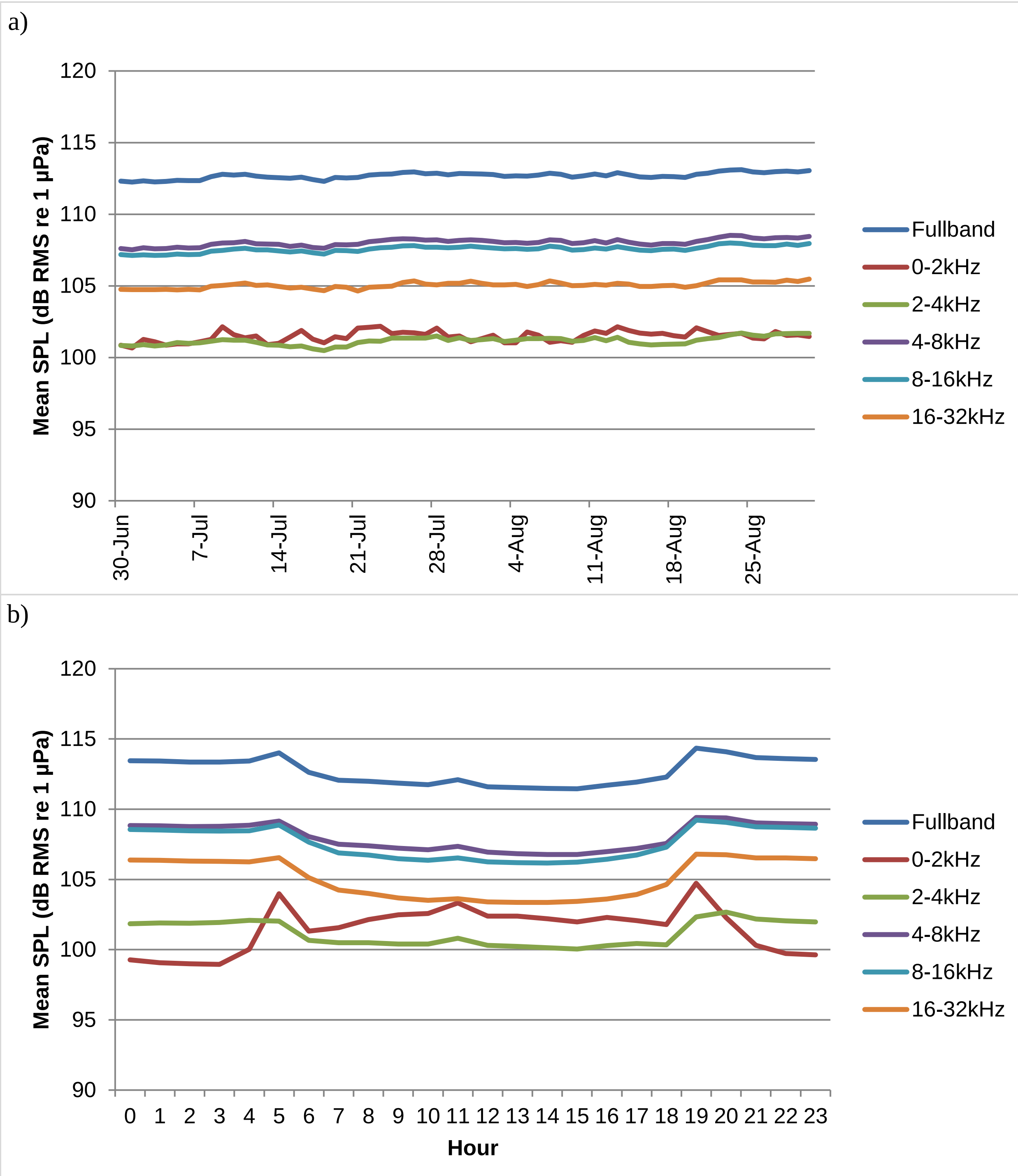


Figure A3. Kahekili summer deployment root mean square sound pressure level in 1-octave frequency bands by date from 30 June 2016 to 30 August 2016 (a) and by hour of day from 0000 to 2300 h (b)

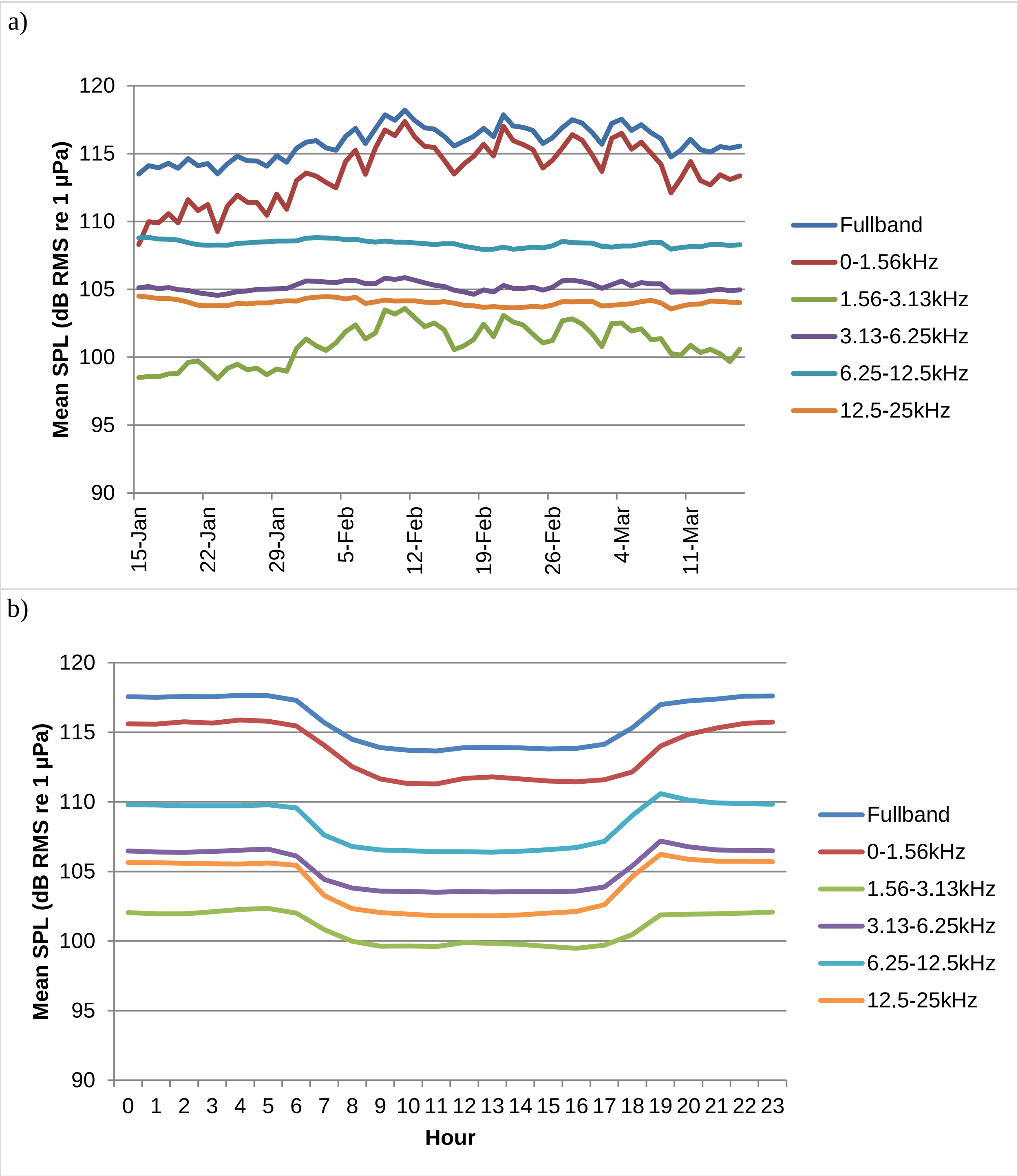


Figure A4. Kahekili winter deployment root mean square sound pressure level in 1-octave frequency bands by date from 15 January 2016 to 16 March 2016 (a) and by hour of day from 0000 to 2300 (b)

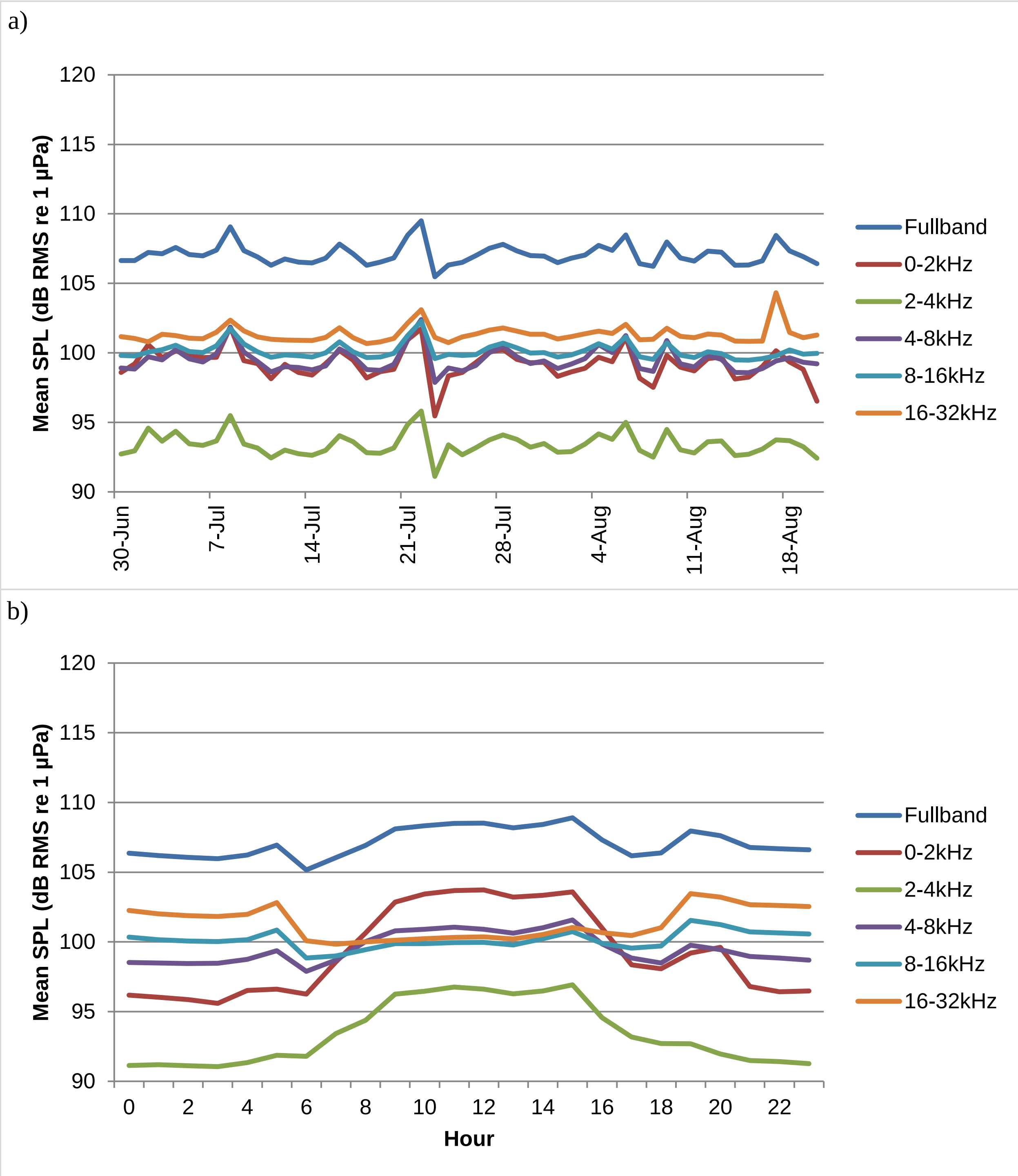


Figure A5. Launiupoko summer deployment root mean square sound pressure level in 1-octave frequency bands by date from 30 June 2016 to 20 Aug 2016 (a) and by hour of day from 0000 to 2300 h (b)

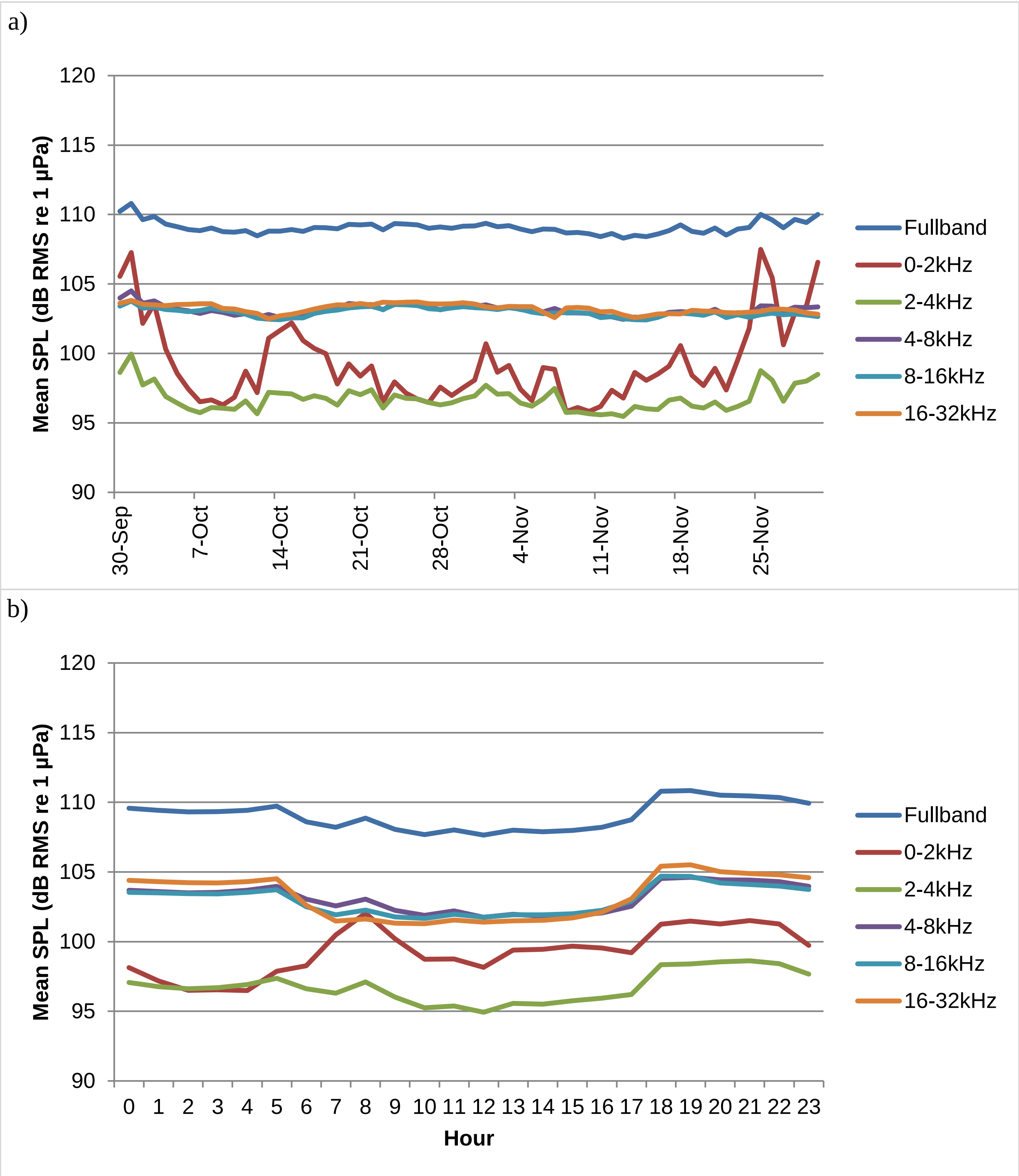
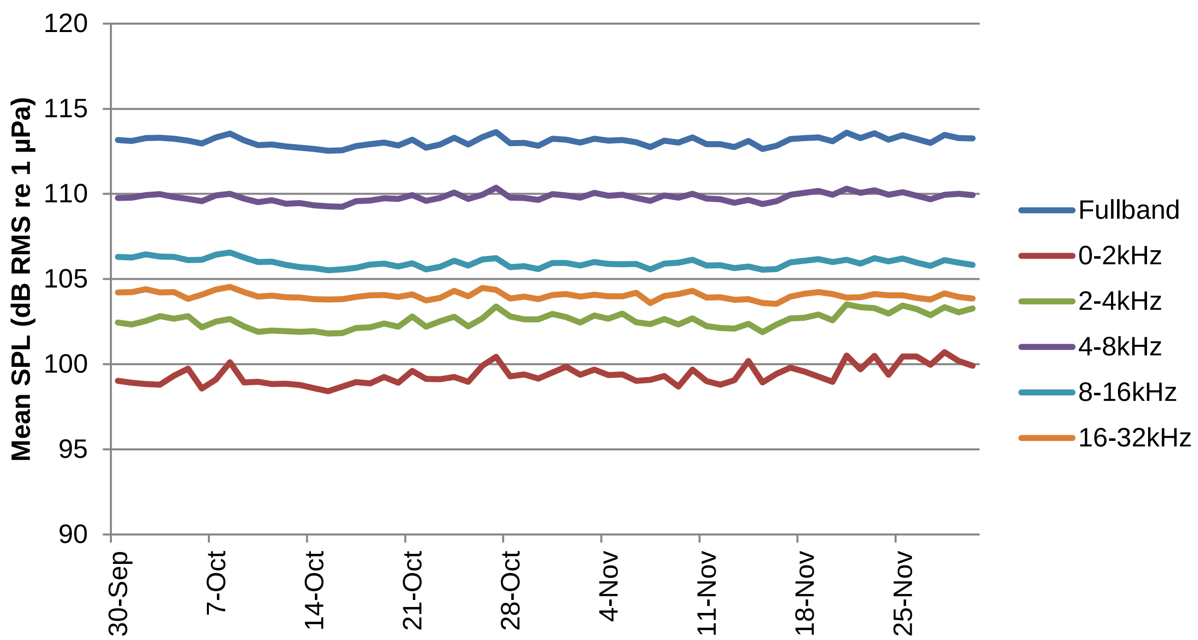


Figure A6. Lōpā fall deployment root mean square sound pressure level in 1-octave frequency bands by date from 30 September 2016 to 30 November 2016 (a) and by hour of day from 0000 to 2300 h (b) a)



b)

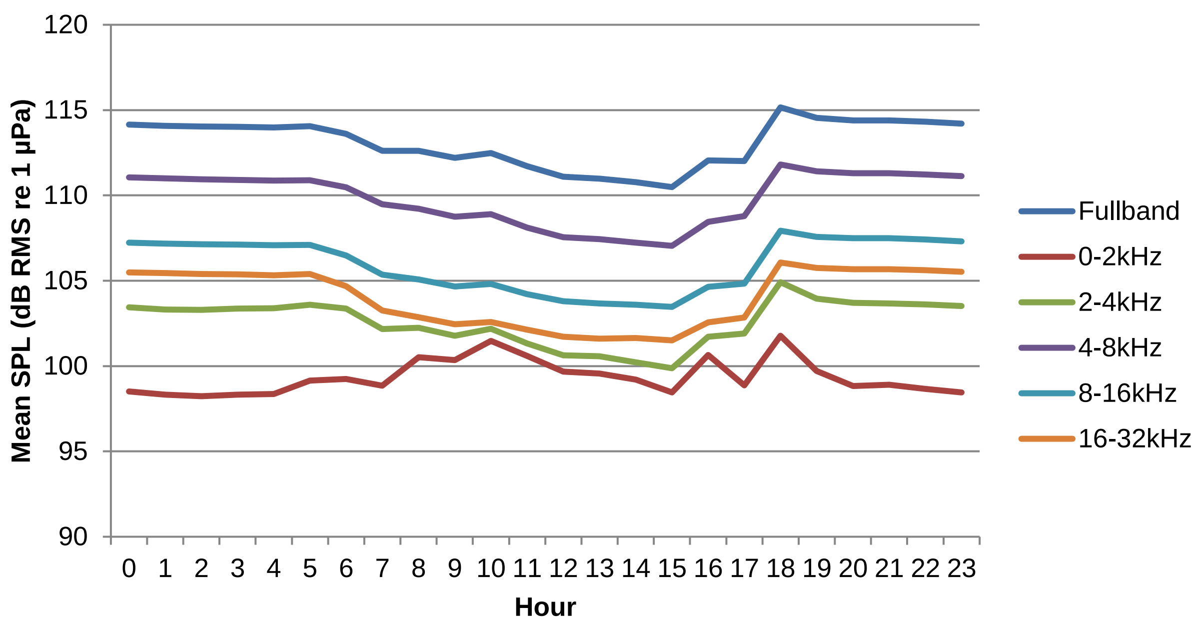


Figure A7. Mānele fall deployment root mean square sound pressure level in 1-octave frequency bands by date from 30 September 2016 to 30 November 2016 (a) and by hour of day from 0000 to 2300 h (b)

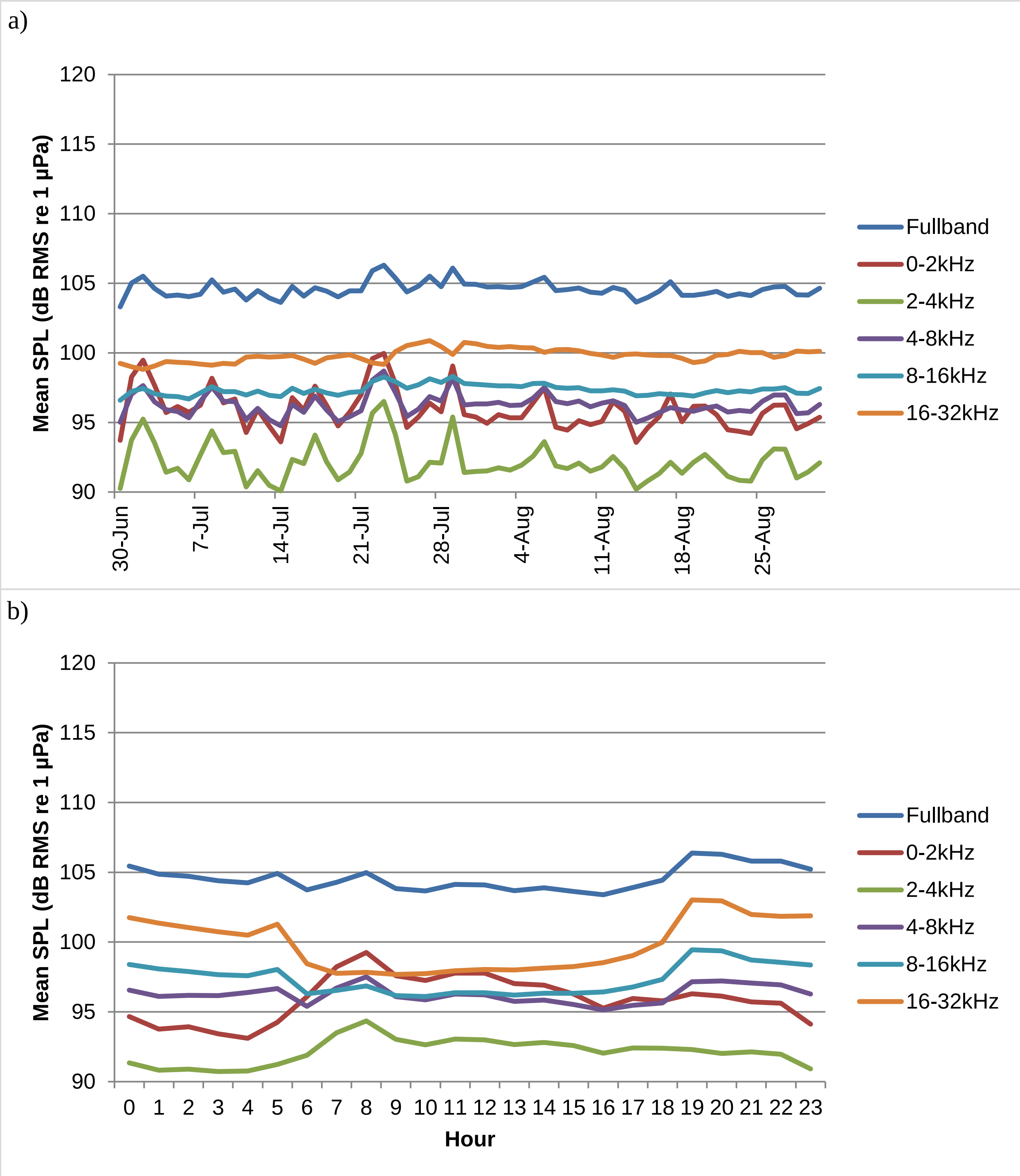


Figure A8. Maui-Lānaʻi summer deployment root mean square sound pressure level in 1-octave frequency bands by date from 30 June 2016 to 30 August 2016 (a) and by hour of day from 0000 to 2300 h (b)

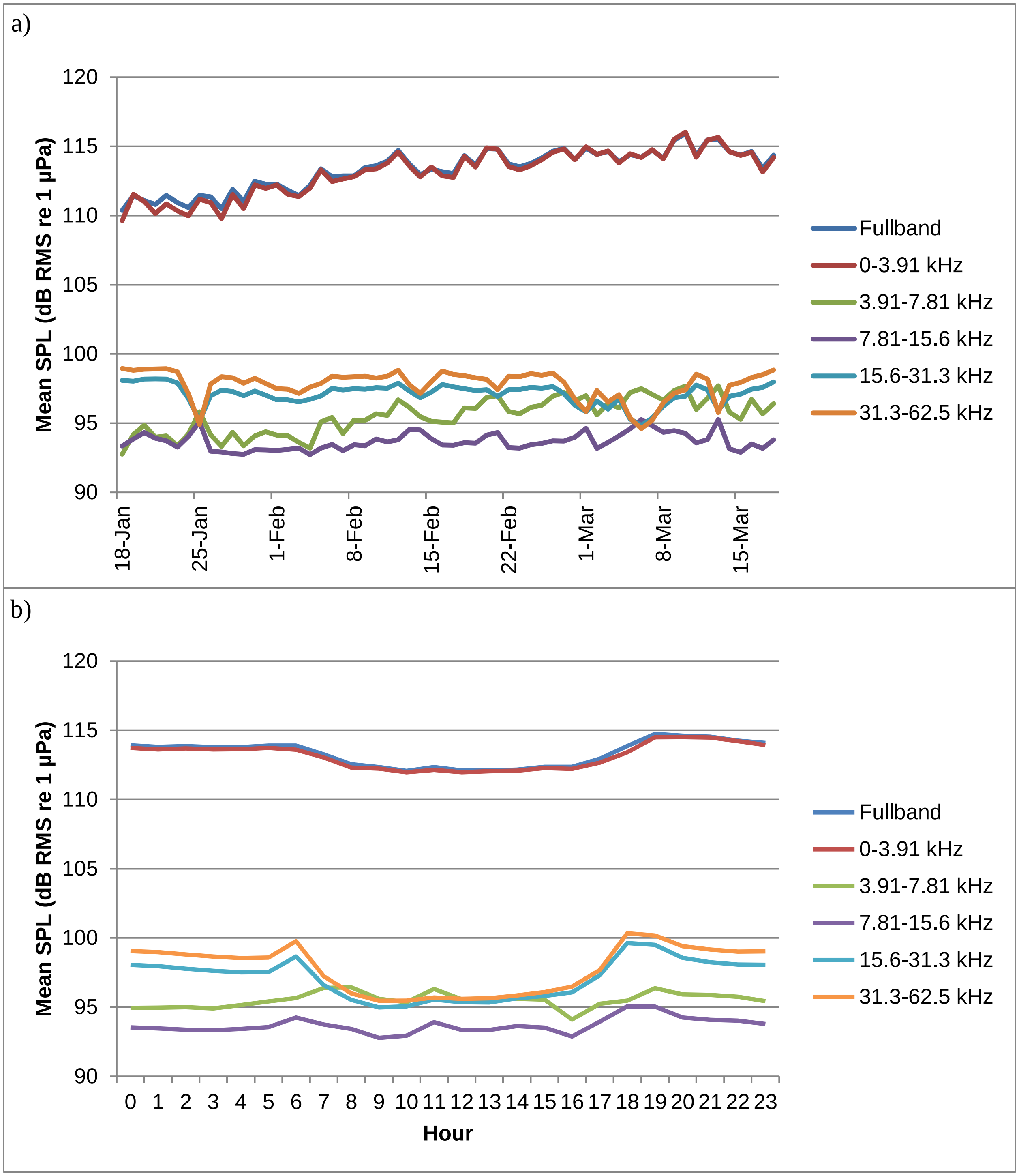


Figure A9. Maui-Lānaʻi winter deployment root mean square sound pressure level in 1-octave frequency bands by date from 18 January 2015 to 18 March 2015 (a) and by hour of day from 0000 to 2300 h (b)

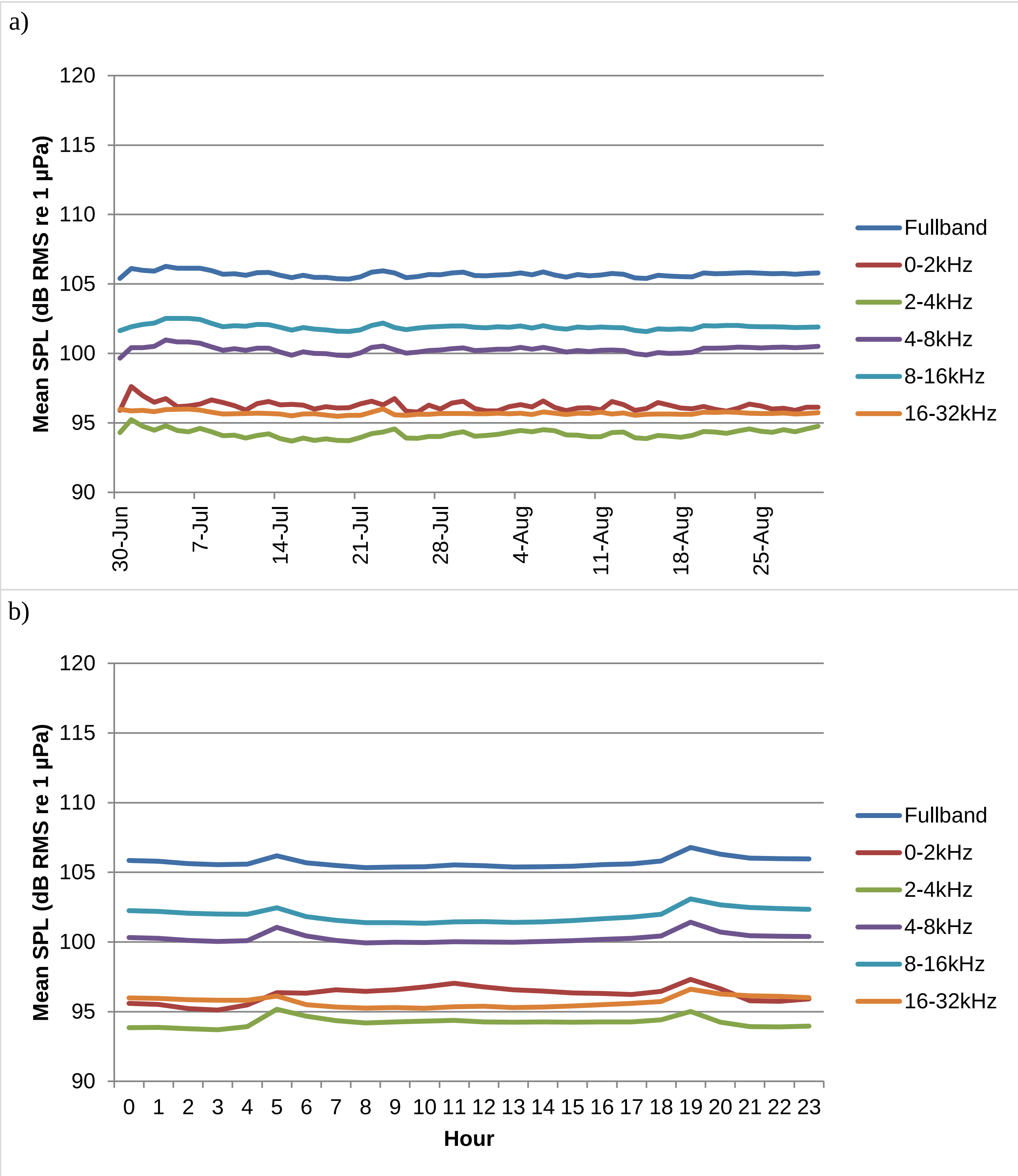


Figure A10. MM17 summer deployment root mean square sound pressure level in 1-octave frequency bands by date from 30 January 2016 to 30 August 2016 (a) and by hour of day from 0000 to 2300 h (b)

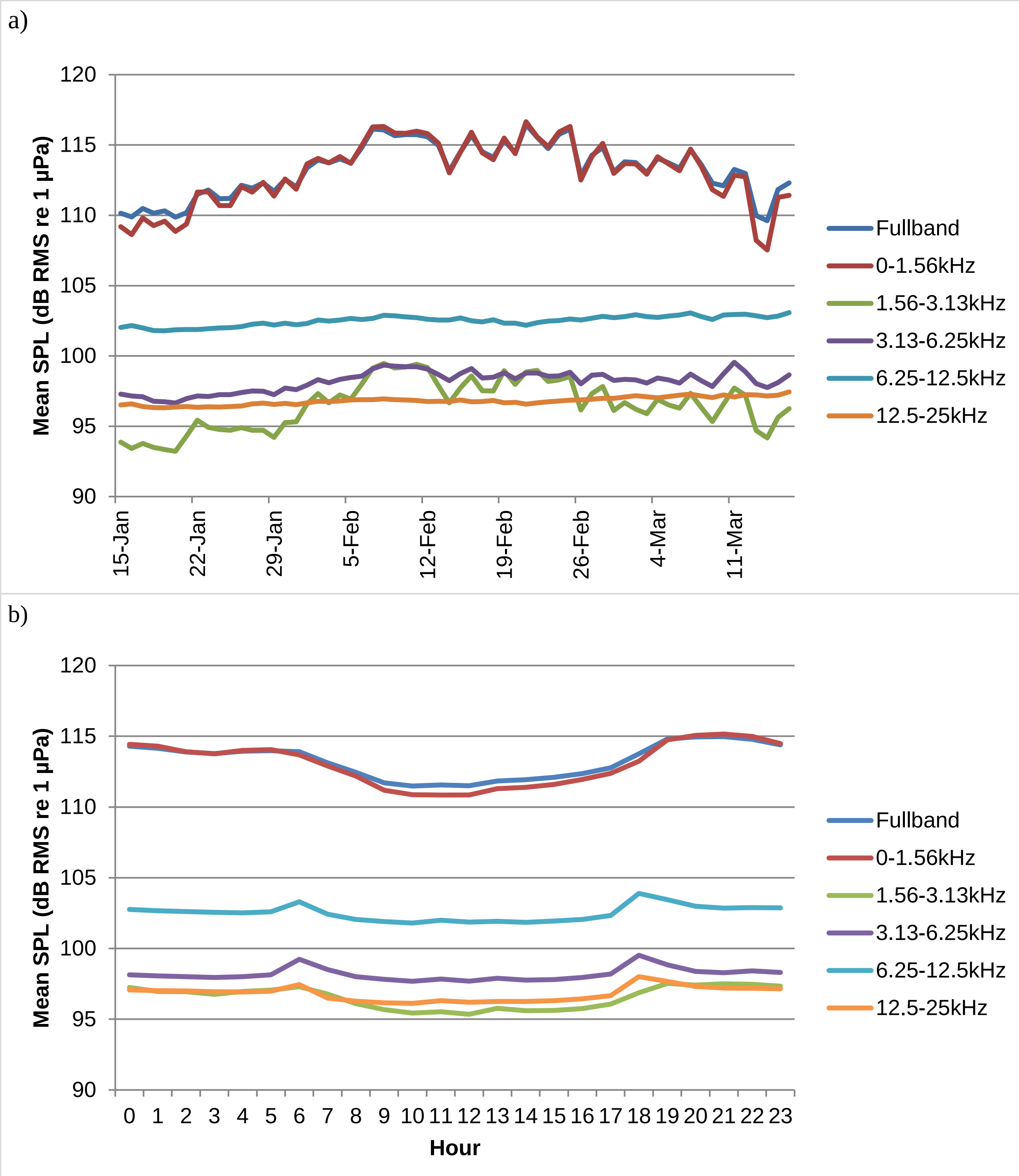


Figure A11. MM17 winter deployment root mean square sound pressure level in 1-octave frequency bands by date from 15 January 2016 to 16 March 2016 (a) and by hour of day from 0000 to 2300 h (b)

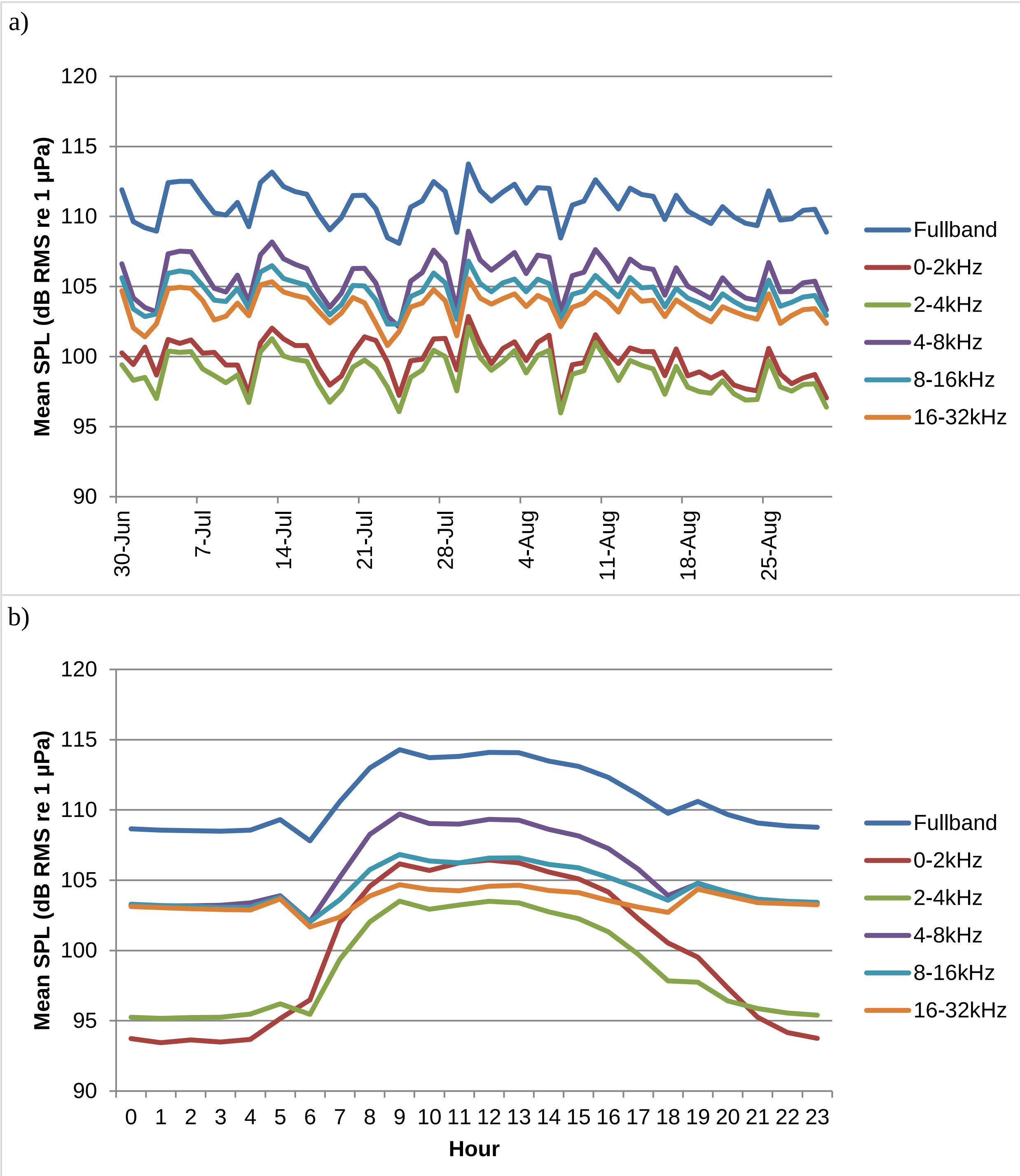


Figure A12. North Mala summer deployment root mean square sound pressure level in 1-octave frequency bands by date from 30 June 2016 to 30 August 2016 (a) and by hour of day from 0000 to 2300 h (b)

Appendix B

Pinger Test

Methods

In August of 2016 tests were conducted for the Maui-Lānaʻi channel, Kahekili, North Mala, MM17 and Launiupoko EARs to estimate their detection radii. For each location the vessel was positioned at approximately 2 km, 1.5 km, 1 km, 0.5 km, and 100 m away from the deployed EARs. An RJE International ARS 100 Pinger was placed in the water over the side of the vessel and programmed to play a continuous series of 0.10-second 4-7 kHz chirps at 145.5 dB re 1 μPa every 5 seconds for a total of 5-10 min. The fundamental frequency range of spinner dolphin whistles is 2-22 kHz with a mid-frequency average of 12.9 kHz and an average source level of 153.9±4.47 dB (Bazúa-Durán & Au, 2002; Lammers et al., 2003). Therefore the pinger signal has a lower frequency and source level than spinner dolphin whistles.

Once the EAR data were recovered, spectrograms of the recordings were scanned for the pinger signal. The vessel GPS track and the known GPS locations of the EARs were used to calculate the distance between the pinger and the EAR at the time of each recording.

Results

The detection ranges for the Maui-Lānaʻi, Kahekili, North Mala, Launiupoko, and MM17 EARs were determined by the maximum distance at which the pinger signal was detected on the EAR recordings. The Maui- Lānaʻi EAR had the greatest detection radius of 2,173.4 m, while the Kahekili EAR had the smallest radius of 534.0 m. The MM17, Launiupoko, and North Mala EARs had radii of 1963.8 m, 1375.5 m, and 1221.2 m respectively (Figure B1).

Discussion

The vast difference in detection range between the Kahekili EAR and the other locations can be explained by the difference in ambient noise. Vessel noise masked most of the pinger signals on the North Mala EAR, except in a small window of low ambient noise. This higher level of background noise is apparent when the root mean square sound pressure levels (RMS SPLs) for each EAR are compared. The North Mala 4-8 kHz octave band had a RMS SPL between approximately 102 and 109 dB, and the 4-8 kHz octave band of the Kahekili summer deployment ranged between 107 and 108 dB (Figure A12-a; A3-a). The same octave band had lower averages which ranged from 95 to 99 dB in the Maui-Lānaʻi summer deployment, 98-102 dB in the Launiupoko deployment, and 100-101 dB in the MM17 deployment (Figure A8-a; A5-a; A10-a). It is important to take the ambient noise into consideration when interpreting the results of dolphin acoustic activity, as there are likely to be some masking effects.

Additionally, because the pinger signal had a lower frequency range than spinner dolphin whistles, as well as a lower source level it is likely slightly overestimating the EAR detection radii as the low frequencies of the pinger signal can travel farther than the upper frequencies of a whistle.

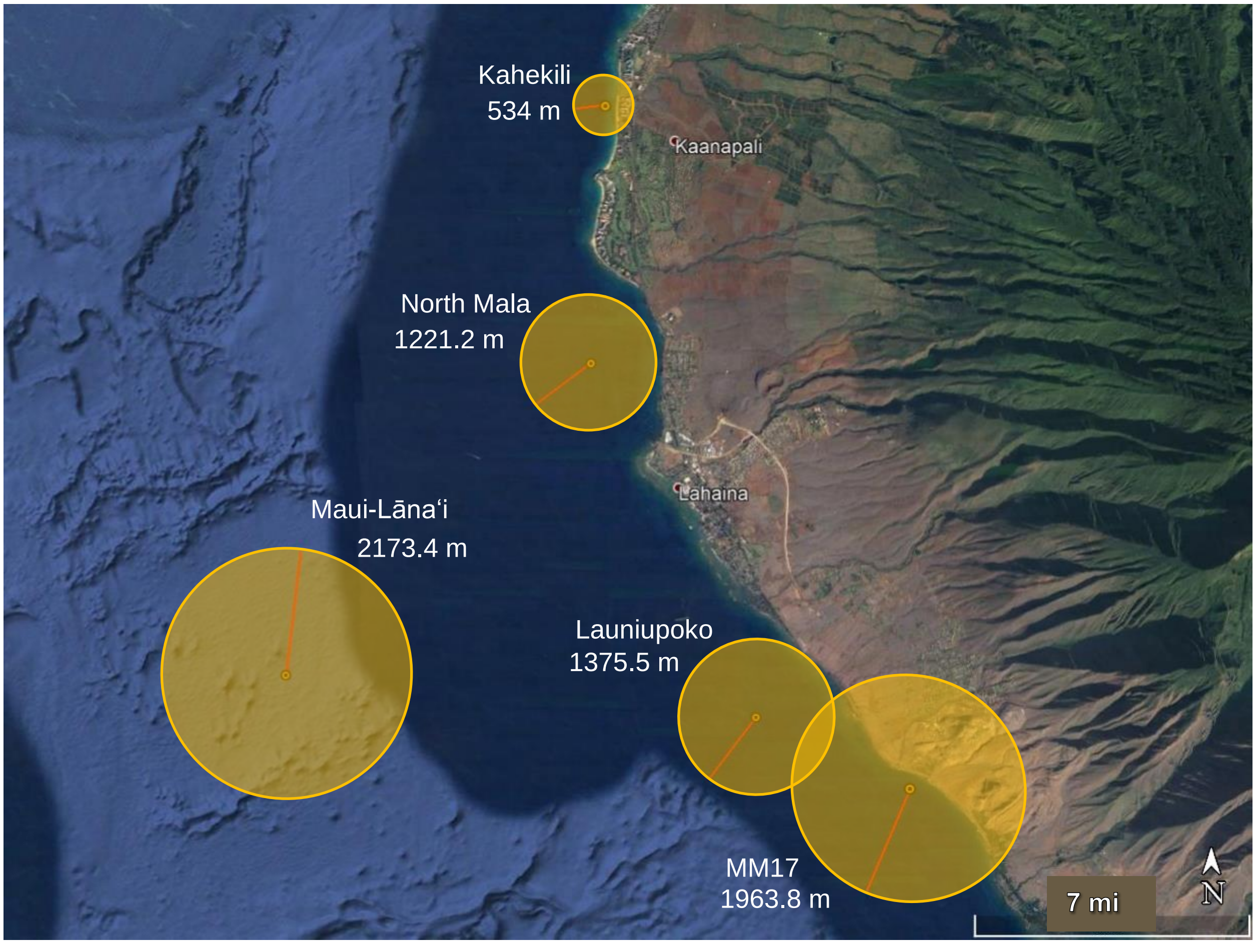


Figure B1. Detection ranges of the Maui- Lānaʻi, Kahekili, North Mala, Launiupoko, and MM17 EARs from the August 2016 pinger tests using a 4-7 kHz signal represented by circles. The points in the center of each circle indicate the location of the EAR, while the red line indicates the radius of the circle which is the maximum distance from the EAR at which the pinger could be detected. Map is centered on -156.6927°, 20.88052°

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